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PROCEEDINGS OF 1969 RELIABILITY-QUALITY CONTROL SENINAR - THEME: "RELIABILITY AND QUALITY: TEAMWORK FOR PRODUCT EFFECTIVENESS"

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PROCEEDINGS OF 1969 RELIABILITY-QUALITY CONTROL SEMINAR

THEME: "RELIABILITY & QUALITY : TEAMWORK FOR PRODUCT EFFECTIVENESS"

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The Committee wishes to express its grateful appreciation to those who have so graciously contributed their time and energy in preparation and presentation of these papers.

In order to assure the continuance of the high level of participation at future seminars sponsored jointly by the ASQC and SRE, a call is hereby issued for papers for the 1970 seminar. Those desiring to contribute papers are requested to contact officers of either the Buffalo Section of the ASQC or the SRE by 1 December 1969.

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AIR BEARING APPLICATIONS IN INSPECTION INSTRUMENT DESIGN

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N69-36727

ABSTRACT: This paper describes applications of linear and rotary hydrostatic air bearings to instruments for inspection gaging. Four particular instrument designs are described in detail. A roundness gage and a unique instrument for measuring height, flatness, and parallelism are described as examples of air bearing applications to standard gaging operations. Two specialized measuring systems, in which the designs depend very critically on the unique air bearing capabilities, are also described. The unique advantages of air bearings in these applications are pointed out in detail.

1. INTRODUCTION

Gas bearings are not new in an historical sense. The hydrostatic gas bearing was developed before World War II, and the hydrodynamic gas bearing was brought to a high state of development within a few years after WW II. However, practical applications of these bearings have emerged very slowly. Although they offer several unique advantages for many potential applications, they have been accepted, generally, only where critical design or performance requirements dictate their use. For example, gas bearing instrument gyros have been used for several years in inertial navigators and autopilots of several types of aerospace vehicles. The gyros measure angular motions, and very high accuracy and reliability are absolutely essential in this application.

Within the past few years interest in air bearings (air is the usual lubricant) has begun to rise sharply throughout the industry. They have been topics of discussion in several professional journals and trade magazines, and applications are emerging at a much faster rate than, say, 10 years ago. These applications are of less exotic nature than the instrument gyros cited above. For example, a currently available muffin fan utilizes a hydrodynamic air journal bearing to reduce wear and drive motor power. In another application a light-duty punch press has been equipped with a hydrostatic air slide to guide the punch motion, with very significant improvements in die wear and production volume.

Precision gaging and inspection has become a most fertile field of application of air bearings within the past few years. Air bearings have several unique capabilities which are very important for mechanizing precise measurements. Chief among these are high motion accuracy, absolute motion repeatability, and frictionless operation. These capabilities have fostered two important kinds of improvements in gaging and inspection instrument designs. First, new instruments have been dsigned for "standard" kinds of measurements, such as height, flatness, parallelism, roundness, concentricity, and contour. The new instruments are faster, more accurate, and more versatile than

their "standard" counterparts. Second, air bearings are giving rise to completely new kinds of gaging techniques, because of their unique capabilities. The instrument designer can rely on highly accurate, absolutely repeatable bearing motions, both linear and rotary. Furthermore, frictionless operation guarantees calibration stability under widely varying operating conditions. These capabilities have opened brand new vistas for creative design of inspection instruments.

Inherent motion accuracy results primarily from the fact that an air bearing distributes its load over a surface area, rather than among several points or lines of contact, as in ball bearings, roller bearings, and the like. The effects on motion accuracy of small irregularities in the bearing surfaces are smoothed out by the area distribution of the load, and because there is no surface-to-surface contact.

Since there is no surface contact, there is no surface deformation under load. The bearing motion then is absolutely repeatable, and it is possible to calibrate errors in the motion and introduce corrections, if necessary.

Since the viscosity of air is very low, there is very little friction even under very high speed operation. Heat generation within the bearing is therefore very small, and there is very little danger that the calibration of an air bearing gage will be destroyed by internal temperature changes under operation.

This paper describes four precision gaging instruments. Collectively, they illustrate applications of both linear and rotary hydrostatic air bearings to a wide variety of stringent inspection requirements. Two of the instruments are for "standard" gaging measurements. The first is a roundness gage, described in section 2, in which an air spindle makes possible roundness and concentricity measurements to an accuracy of a millionth of an inch. The second is a unique device for gaging flatness, height, and parallelism. The arch-shaped instrument, described in section 3, floats on air pads over a surface plate, and maintains high accuracy with complete mobility. The versatility of this instrument has given rise to other inspection applications as well. In both these instruments, the air bearings have given rise to new design principles which permit very accurate and very rapid measurements compared to "standard" gaging techniques.

The other two examples are specialized measuring systems in which the designs depend critically on the unique capabilities of air bearings. Section 4 describes a set of two machines which measure angular misalignments of small rocket engines in the post-boost vehicle of the MINUTEMAN III ICBM. These measurements are quite out-of-the-ordinary, and the design principles of the machines are quite unique. Section 5 describes a system which uses three gaging heads to simultaneously measure roundness and concentricity of two cylindrical surfaces and perpendicularity of a flat surface on the same machined part. An air spindle turns the machined part very accurately, and air slides index the gaging heads into the measuring positions.

These four examples are typical of air bearing applications in the field of precision gaging and inspection. Other good examples exist, and more are currently under design, but the ones chosen typify not only the applications of air bearings, but also the current trends in gaging instrument design. Section 6 contains some closing comments about these trends and projections about the future applications of air bearings in this field.

2. ROUNDNESS GAGE

Figure 1 shows an instrument for roundness and concentricity measurements. The part to be measured is mounted on the air spindle table, held by its own weight or by a holding fixture. The electromechanical probe is adjusted against the surface to be measured, and it remains at a fixed radius from the spindle axis while the spindle is turned at a constant rate by a synchronous drive motor. The probe then reads variations in the radius of the part as it turns. The probe readout is simultaneously displayed on a meter and recorded on a polar chart.

Very high accuracy probes are available, so that the fundamental accuracy limitation of the instrument is determined by the spindle. There are three important sources of error to consider: spindle runout, spindle tipping, and centering of the part to be measured on the spindle table. Runout and tipping are inherent spindle errors, almost impossible to control or correct if they exist. Runout, which is a lateral motion of the spindle as it turns, appears directly as a radius error. The air spindle in this instrument exhibits very low runout. A standard model has a T.I.R. guaranteed less than .000005 inch, and a special model with a .000001 inch T.I.R. is available.

Spindle tipping gives rise to a coning motion, that is, the spindle precesses as it rotates, like a gyroscope. The resulting probe readout error is very complex mathematically, but for roundness measurements it closely resembles a part centering error, and can be corrected like a centering error. For concentricity measurement, however, tipping always yields a fictitious concentricity error. Tipping is usually caused by a center-of-gravity offset in the part to be measured. If the c.g. is displaced from the spindle axis, a torque is applied to the journal bearing. High journal stiffness is necessary to keep the tipping small. Stiffness of the order of a microinch/lb is obtained in this spindle, which has a journal 5 inches long and 3 inches in diameter.

Part centering error is not an inherent spindle error, and it can be detected and corrected. The spindle table has both leveling and centering adjustments, but for high precision gaging it is very difficult to make fine adjustments of a few millionths of an inch with the centering screws. The instrument is therefore equipped with "electronic centering", which allows the trace on the polar chart to be centered when the part is actually off center. The operations involved are quite simple. The off-center trace is first observed on the polar chart. A phasing adjustment is then made, which aligns a special mark pulse with the direction in which the trace is to be moved on the chart. Finally, a simple adjustment of the amplitude control moves the trace to a centered condition.

The unique contribution of the air bearing to this instrument is high accuracy with large load capacity. The runouts quoted above are not achievable with ball or roller bearings. The spindle has been tested with loads to 300 lbs.

For concentricity measurements, this instrument can be equipped with two probes and with electronics for selectable single or differential readout (i.e., probe A, probe B, or probe A minus probe B).

3. METRO/ARCH

Figure 2 depicts a unique new instrument which is used on a surface plate for gaging height, flatness, and parallelism. The two feet which contact the surface plate are air bearings, so that the entire instrument floats over the plate on two air pads. Each pad measures 4 inches by 6 inches so that vertical stability

is good, and the instrument has complete mobility over the surface plate while very accurately maintaining the probe at the reference height.

The interior of the arch is 20 inches wide by 10 inches high. The probe support post can be inverted to reach heights of 2 feet or more.

The accuracy of the instrument is determined entirely by the quality of the surface plate. Since the air pressure to the two pads is closely regulated, each pad floats at a constant height above the plate. Therefore, gaging accuracy is limited only by the undulations in the surface plate over which the instrument floats. Measurement accuracy of .000020 inch, with even better measurement repeatability, has been demonstrated on a laboratory grade surface plate. The Metro/Arch furthermore can be used to check the surface plate accuracy.

In another inspection application, a microscope has been mounted on the Metro/Arch in place of the probe, and the instrument is then used for visual inspection of very small parts laid on the surface plate. Since an accurate height reference above the surface plate is maintained, the microscope remains properly focused as the instrument is moved to view successive parts. A significant increase in inspection speed is obtained, since many parts can be laid on the surface plate and inspected sequentially without intermediate adjustments.

4. ROCKET NOZZLE MISALIGNMENT MEASURING SYSTEM

Figures 3 through 6 are views of two very specialized machines for measuring angular misalignments of rocket nozzles in the post-boost vehicle of the advanced MINUTEMAN III ICBM. The post-boost vehicle, as its name implies, goes into operation after the booster engines have burned out. Its mission is to deploy the several warheads which the missile carries toward their intended targets. It contains the missile guidance and control system and a propulsion system which performs necessary attitude maneuvers, applies final guidance corrections to the warheads, and executes deployments.

Figure 3 is an overview of the two measuring machines. The nearer machine checks angular misalignments of small attitude control nozzles which open through ports in the missile skin. The farther machine in figure 3 checks alignment of a larger axial thrust engine, and a post-boost vehicle mounted in gaging position can be seen on this machine. Also visible in figure 3 are the control consoles, which control the gaging operations and display the measured errors.

Figure 4 is a closer view of the post-boost vehicle mounted in gaging position on the attitude engine measuring machine. The attitude rocket nozzles can be seen in the ports in the missile skin. These engines control pitch, yaw, and roll attitudes, and each has a preferred orientation relative to the missile body. A large rotary table mounts the missile section and indexes the nozzles in front of the gaging head. The bases and vertical pillars of both machines are granite for strength and stability.

The gaging head on each machine has six degrees of freedom, three linear and three rotary. The probe head assembly is mounted on a compound rotary table which can be indexed in both azimuth and elevation. (Figure 5 shows a closeup view of the probe head mounted on the rotary table on the axial engine measuring machine. The probe heads on both machines are nearly identical.) This table in turn is mounted on a two-degree-of-freedom linear air slide assembly, partially visible in figure 4. Precision lead-screws drive the vertical and horizontal slides, and precision encoders allow the slides to be digitally positioned with a resolution of .001 inch and an accuracy of about half a tenth over

full scale ranges of 10 inches horizontally and about 15 inches vertically. The vertical slide is counter-weighted to relieve the load on the vertical precision lead-screw. Another linear degree of freedom is a linear air slide which allows the probe head to advance into the nozzle throat, as shown in figures 5 and 6. Finally, another rotational degree of freedom is a continuous rotary sweep of the inside of the nozzle throat by the probe tip. Air journals are used to mechanize the sweep rotation. The sweep motion is motorized for automatic operation, and also manually controlled for setup. The knurled twist-wheel and motor are visible at the rear of the probe head in figures 5 and 6.

The machines measure the deviations of the nozzle orientations from their nominal (or design) values. The first step in the gaging operation for each nozzle is to set the probe head to the correct nominal position. This involves setting the azimuth and elevation angles on the compound rotary table and setting the linear and vertical slides to the correct positions to allow the probe tip to be advanced into the nozzle. The probe tip is then advanced to a depth set by an index bar, as shown in figures 5 and 6. The line along which the probe tip advances is the nominal nozzle axis, that is, the reference from which the alignment error is to be measured.

The sweep action determines the center of the circle swept by the probe in the following way. If the probe sweep axis is not precisely aligned with the nozzle center, the probe presses harder against the nozzle wall on one side of its sweep than on the other. The probe signal is resolved electromechanically along two axes in the sweep circle. The two resolved signals are then processed electrically to read out the displacement of the nozzle centerline from the circle center along each axis. Meters on the control console display the error.

The sweep operation is performed at two positions inside the nozzle, the first to establish a reference centerline, and the second to read the nozzle misalignment. At the first reference position, if the sweep reveals a centering error, the vertical and horizontal slide positions are adjusted to null the error. The amounts by which the slides are moved are linear position errors of the nozzles from their reference coordinates. When the reference has been established, the probe head is retracted to a second position within the nozzle, and a second sweep operation is performed. The centering error read out in this second position is the nozzle misalignment.

The gaging apparatus described above is large and heavy, and the ranges of the motions are large. Structural distortions are unavoidable under such conditions. Elaborate alignment and calibration procedures have been designed for the machines, and adjustments for the structural distortions are designed into the machines. The repeatability of the air bearing motions is the basis of these calibration procedures. Accuracies of .000050 inch per foot have been demonstrated over the range of linear travel of the gaging head. Overall angular measurement accuracy is about one arc-minute. The repeatability demonstrated by both machines is much better than the quoted accuracies.

5. SPECIALIZED SYSTEM FOR GAGING ROUNDNESS, CONCENTRICITY, AND PERPENDICULARITY

Figures 7 and 8 show a device which is specially designed to gage roundness, concentricity, and perpendicularity of surfaces on a critical machined part. This is a single-purpose instrument which makes use of three probe heads to perform the gaging operations simultaneously.

Figure 7 is an overview of the entire instrument, and figure 8 is a closeup view of the measuring heads as they address the machined surfaces.

The machined part is turned on a precision air spindle, visible in figure 7. (In the production set-up a master jig on the spindle table will hold the part centered to within the gaging tolerance.) Two of the probe heads, the farther two in figures 7 and 8, measure the roundness and concentricity of the two surfaces which they contact. Note that these two probe heads are mounted on a single support stand, so that they are simultaneously indexed into and out of gaging position. The third probe head, the nearest one in the two figures, measures both perpendicularity and flatness of the surface which it contacts.

The probe support stands are mounted on air slides, which precisely position the gage heads for the measurements. Positioning repeatability is absolutely essential to the gaging operations, and the slides easily hold a positioning accuracy of .000010 in all critical directions. The roundness/concentricity gage slide is actuated by an air piston. The operator advances or retracts the gage head by pushing an appropriate button on the control console. The slide advances against an adjustable mechanical stop, set so that the probe tips are correctly positioned against the cylindrical surfaces. The air piston actuator has been specially designed to have a "cushioned" approach to the mechanical stop. As the slide travels forward, air is trapped in a reservoir and acts as a spring to slow the slide motion as the stop is approached. The actuating piston moves the slide against the spring and holds it firmly against the stop during the gaging operation. The slide repeats to better than .000010 in all three directions.

The perpendicularity gage slide is positioned manually by means of the twist-knob shown in figure 8. Perpendicularity of the flat surface is measured with the probe tip positioned at a fixed radius near the outer edge of the surface, and with the spindle turning. Flatness is measured by drawing the probe tip across the surface in a radial direction, and the spindle may be stopped or turning for this operation. As the probe is advanced onto or withdrawn from the flat surface, the probe tip rides over the sharp shoulder between the flat and cylindrical surfaces on the machined part. The surface height tolerance and the slide positioning accuracy are such that this takes place without the operator having to touch the probe tip.

Figure 7 also shows the control console, which controls air pressure, slide position, and spindle drive power, and reads out the probe signals. The meter visible at the left on the console indicates perpendicularity/flatness error, and the meter at the right indicates roundness/concentricity error. Roundness error is read by selecting signal from one probe only, and concentricity is read from the difference of the two probe signals.

6. CLOSING COMMENTS

Quality control engineers are well aware that inspection operations are "bottlenecks" in many production processes today. Sophisticated product designs and intensive quality control naturally require more inspection accuracy and complexity than was necessary only a few years ago. Furthermore, high volume, automated production has established a critical need for more inspection speed. On the other hand, human judgement is an essential element in almost all inspection procedures. Inspection is therefore almost always a manual operation, hence time-consuming and subject to human error.

These diverse requirements are establishing clear trends in the designs of new gaging and inspection instruments. The requirements for speed and complexity are leading specialized instrument designs - sometimes specialized to a particular machined part or assembly, as in the examples in sections 4 and 5. Speed is gained by designing out wasted motions, and by mechanizing more than one gaging operation simultaneously. Since a human usually performs the inspection, much attention is being devoted to the man-machine interface. Easy-to-read displays directly indicate the parameters which the inspector must know (often requiring considerable signal processing between the probes and the display devices to obtain these parameters). The object of each design is to provide the human operator an instrument which is simple to use (though perhaps very complex internally) and which gives exactly the information he needs to form his judgement. If the instrument performs the tedious gaging operations and does the necessary arithmetic, then the human operator's efficiency is increased and his chance of error is diminished.

New advances in electromechanical and electro-optical technologies are much in evidence in new instrument designs. These technological advances are being employed to increase accuracy, to optimize instrument operational designs, and to improve the man-machine interface. For example, laser probes are now being used for extremely high resolution gaging. Fiber optics are now being used to pipe external scale readings and displays to the <u>insides</u> of microscope eyepieces, so that an operator can keep an object in view and read the measurements simultaneously.

Air bearings fall into this category of technological advances. They provide the instrument designer with very useful capabilities, accurate and repeatable motions with excellent calibration stability. These are most valuable attributes, and air bearings should become more widely used as time goes on.

FIGURE CAPTIONS

<u>Figure 1</u> - Roundness gage equipped with air bearing spindle, polar chart recorder, and electronic centering.

<u>Figure 2</u> - Metro/Arch - mobile, air floated device for gaging height, flatness, and parallelism.

<u>Figure 3</u> - Rocket nozzle misalignment measuring system for MINUTEMAN post-boost vehicle, showing the attitude engine measuring machine in the foreground and the axial engine measuring machine with missile section mounted for gaging.

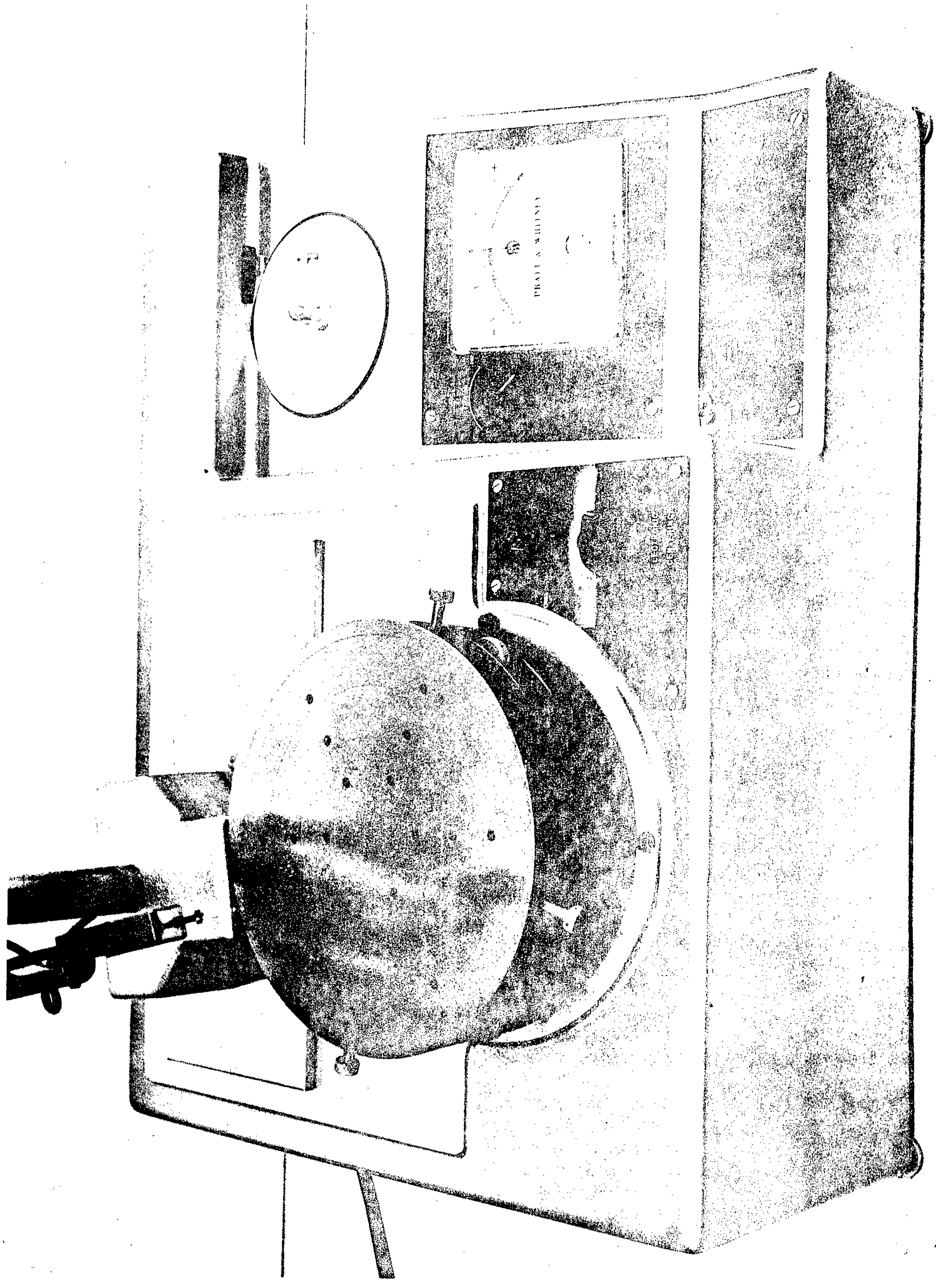
<u>Figure 4</u> - Closer view of attitude engine measuring machine with missile section mounted for gaging.

<u>Figure 5</u> - Closeup view of axial engine measuring head, with probe retracted from nozzle.

<u>Figure 6</u> - Closeup view of axial engine measuring head, with probe extended into nozzle.

<u>Figure 7</u> - A specialized system designed to gage roundness, concentricity, and perpendicularity of surfaces on a critical machined part.

<u>Figure 8</u> - Closeup view of the probe heads addressing the machined surfaces.



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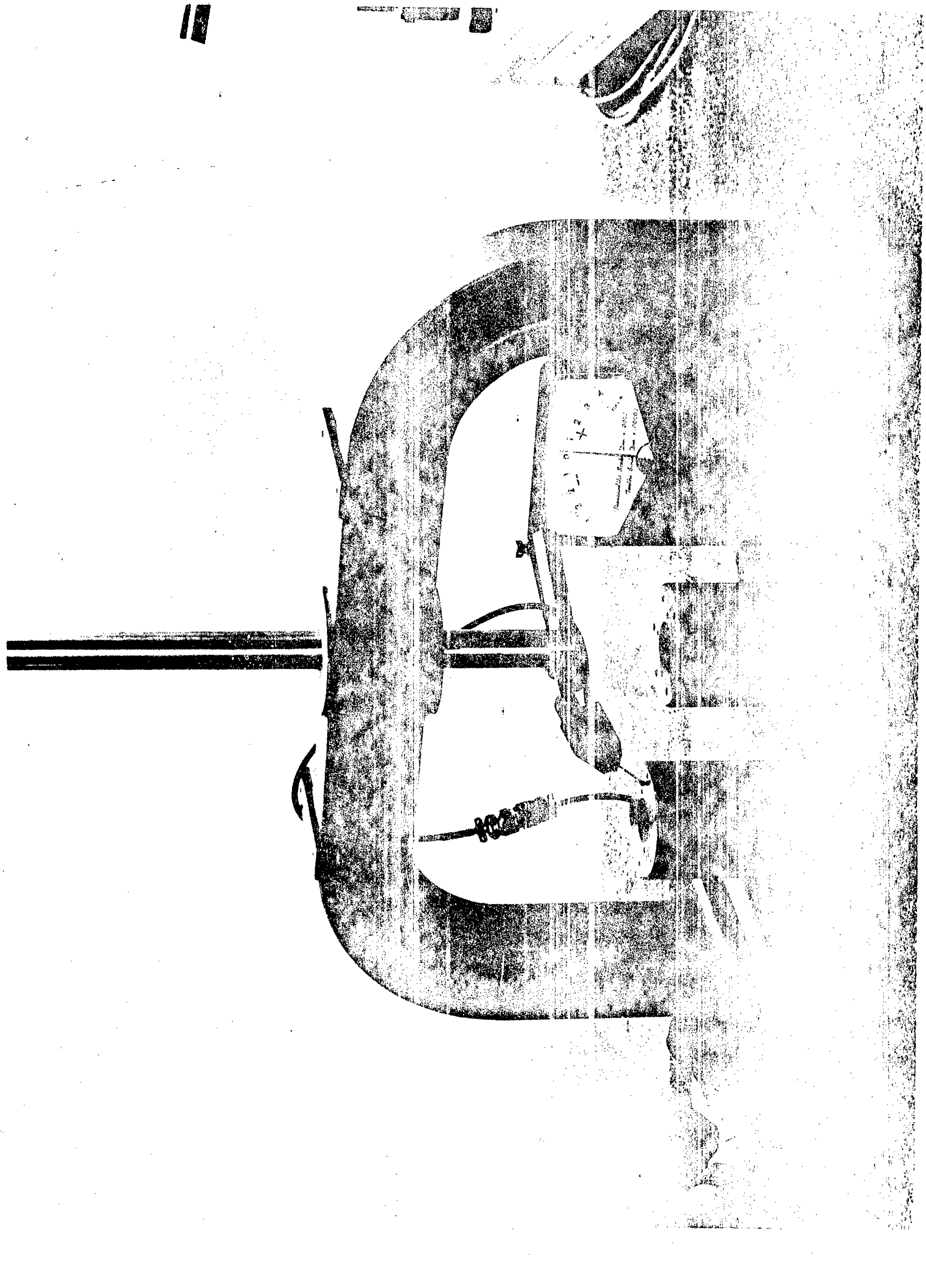

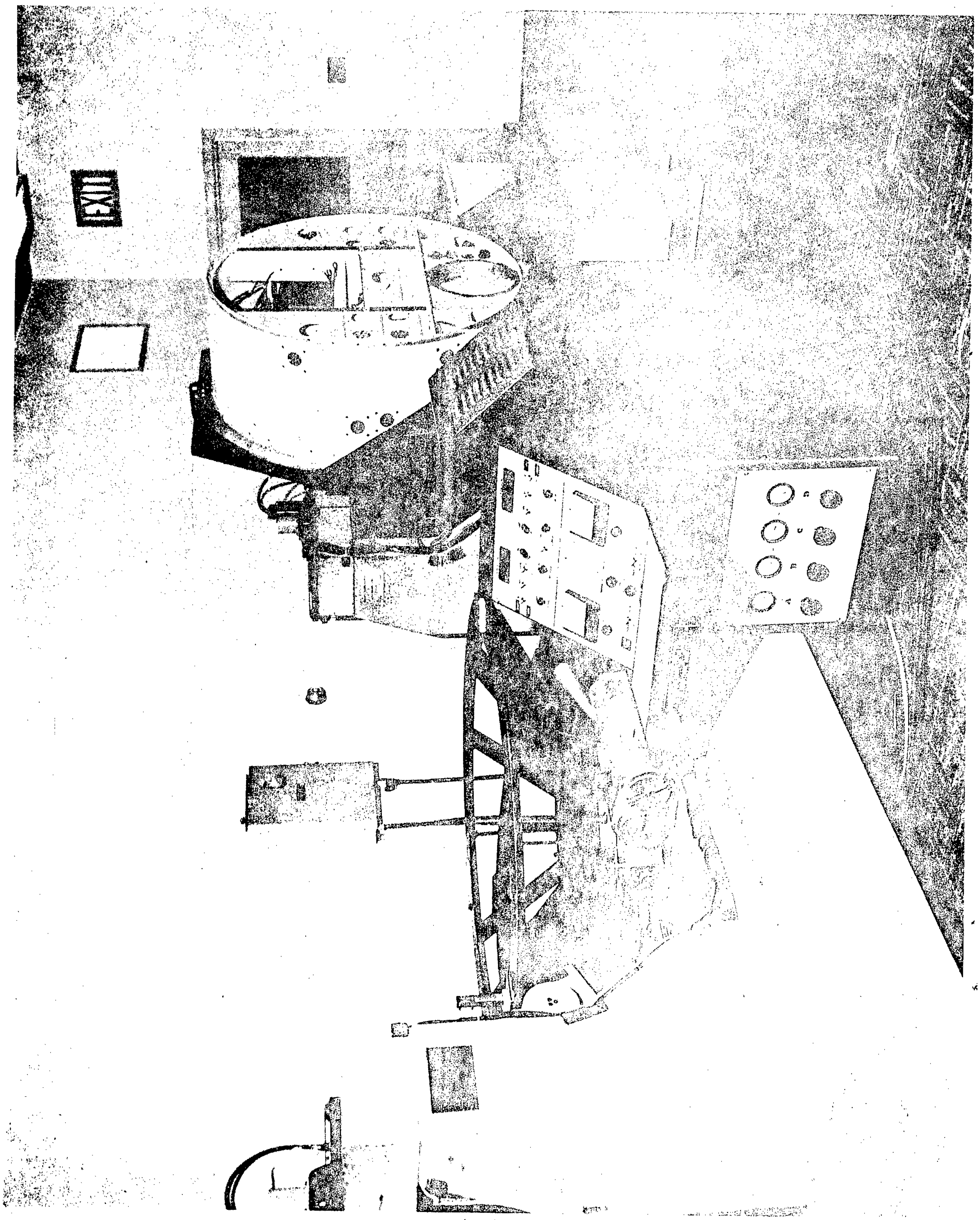
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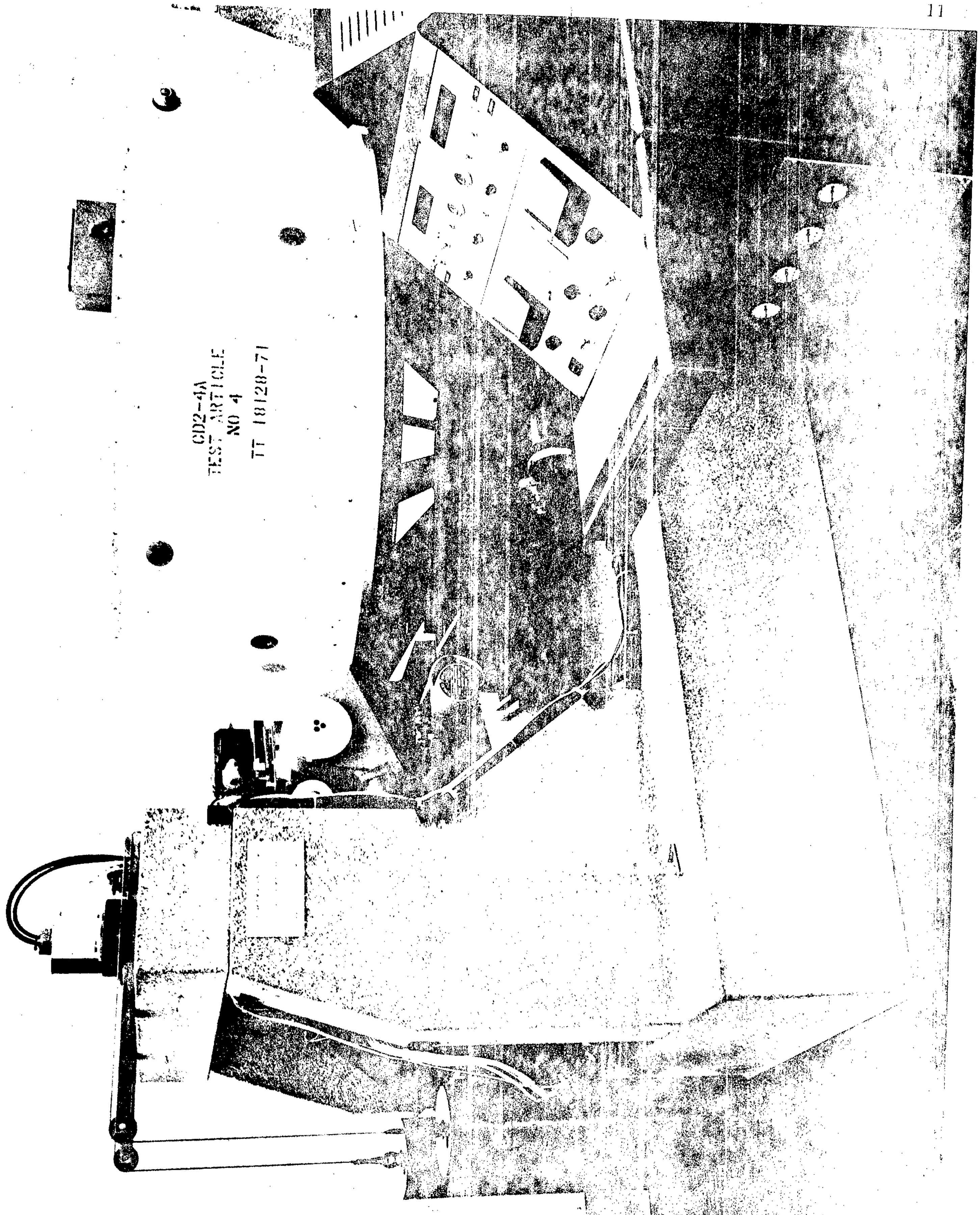
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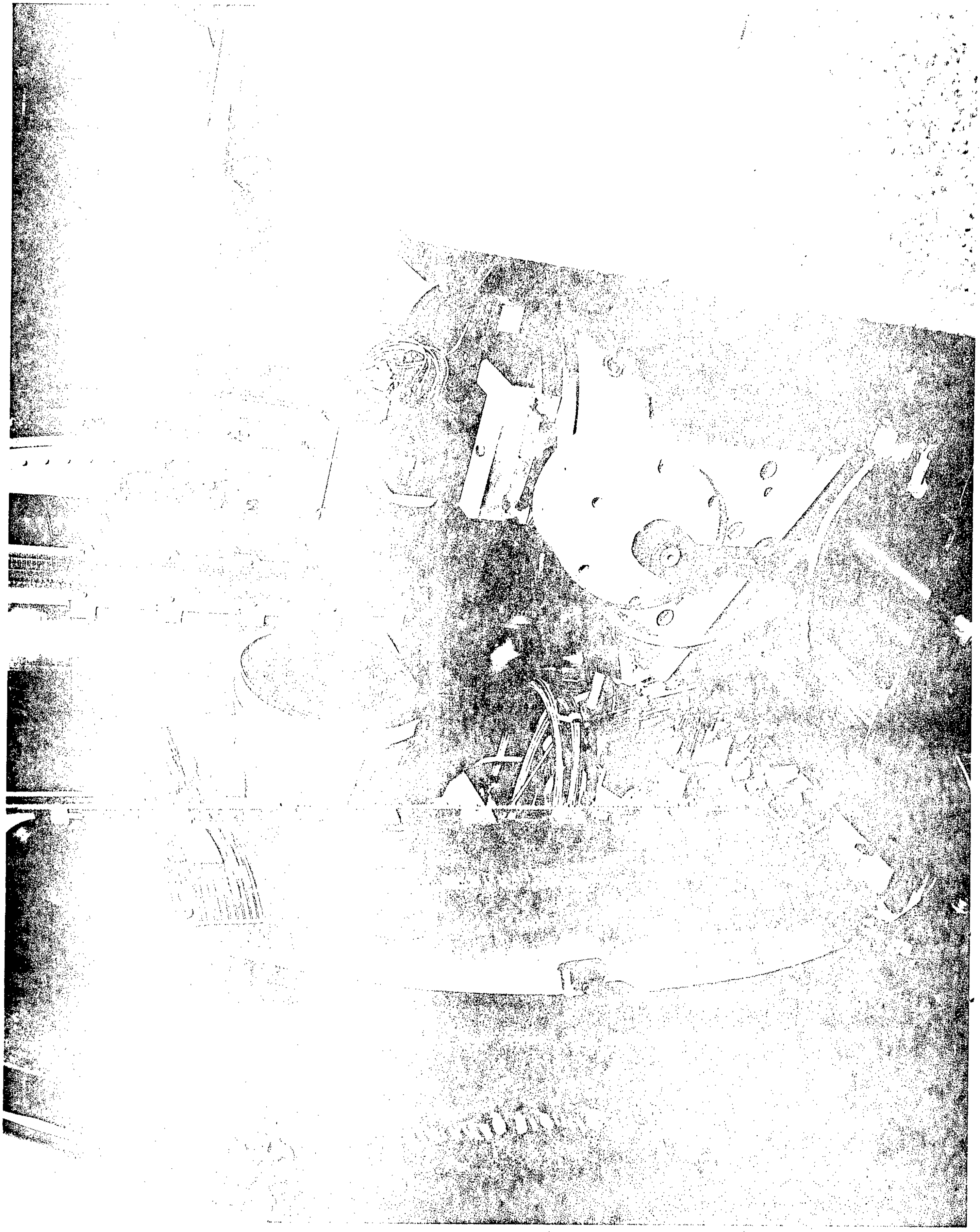

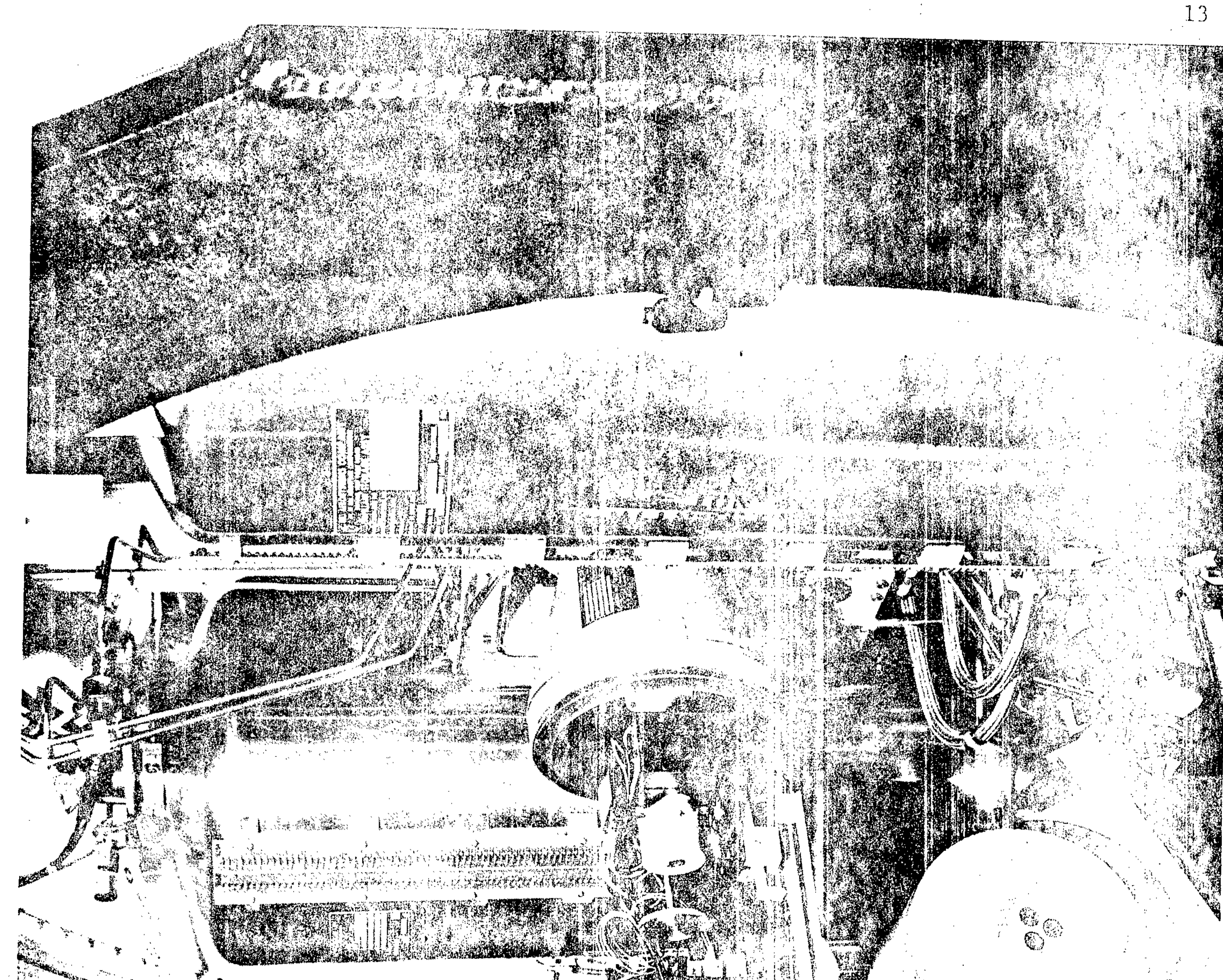

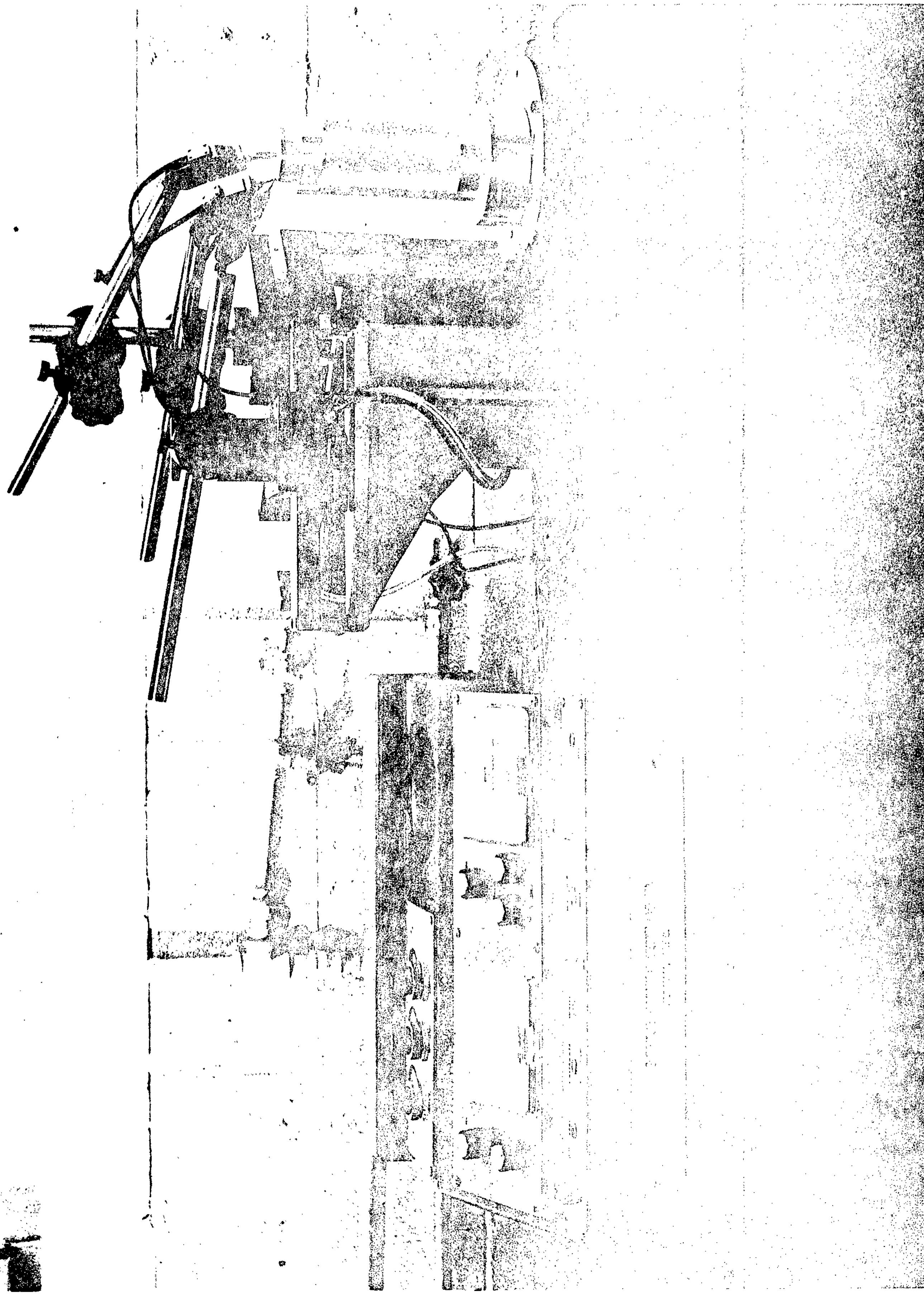

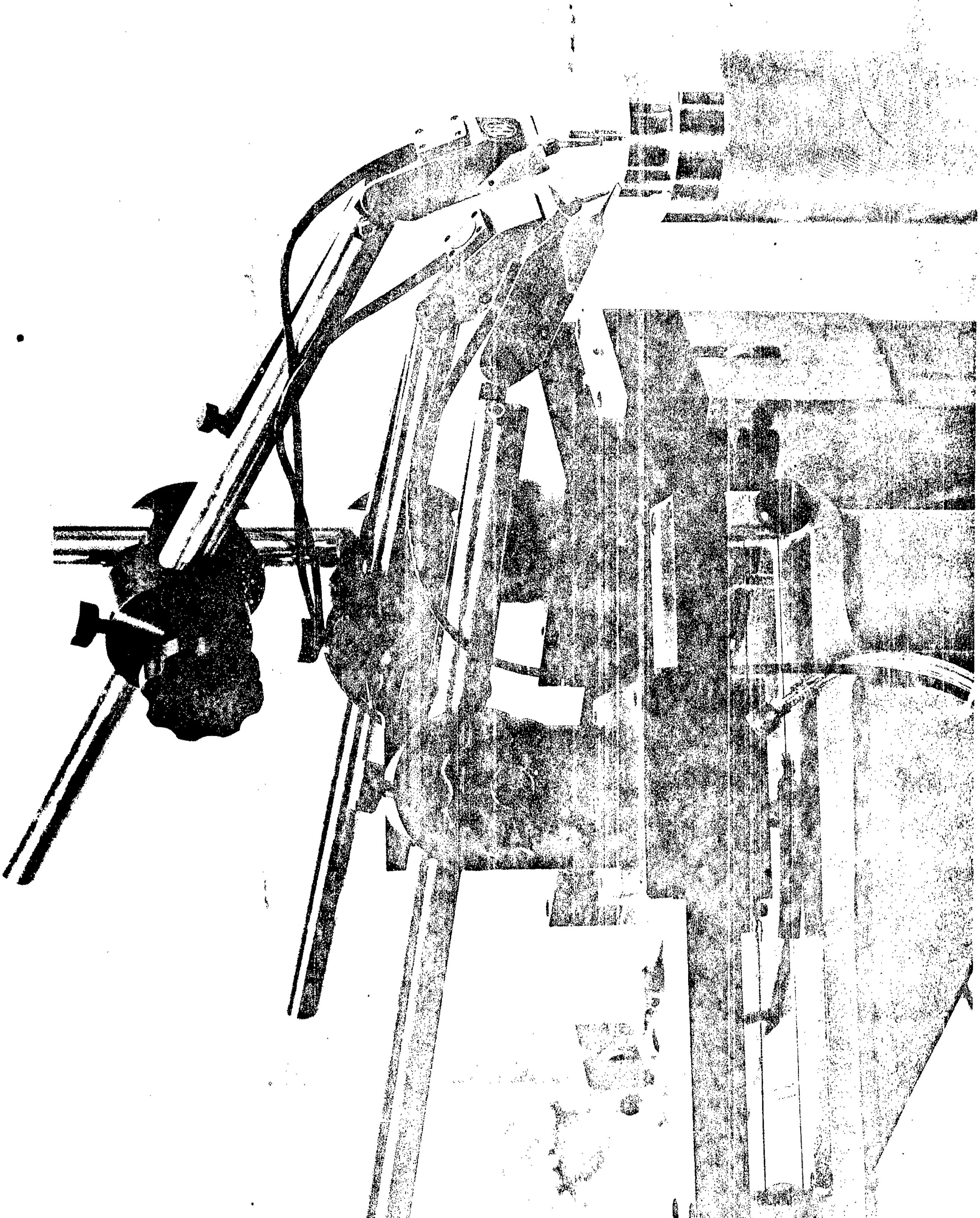

INTERFACE OF QUALITY TO SALES AND MARKETING

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N69-36723

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SUMMARY: The role Quality Assurance people should or must play in the marketing and sales efforts will vary somewhat depending on the type of product being sold, however they do have responsibilities in this area which are sometimes not emphasized. The role of sales and marketing personnel in the overall quality effort will also vary depending on the product and organizational structure, however the two do have responsibilities that they must assume. Some of the roles both should play will be discussed below as well as the background and organization of the author's company to put the remarks in perspective.

BACKGROUND

AMAX Specialty Metals produces zirconium and zircaloy fabricated shapes which are primarily used in the nuclear power program. The prime products are zircaloy ingots, flat rolled products, tubing, wire and forgings. The major customers are approximately equally divided between government subcontracts for the U. S. Navy nuclear program and the rapidly growing commercial power programs. Most orders received are very large with fairly complicated specifications that must be thoroughly understood before quotations can be made or orders initiated. The product value is high and the test procedures are sometimes not well documented.

ORGANIZATION

The organization chart is shown below and as can be seen, the quality organization reports through a separate line to the General Manager than the Production Manager. The inspection function is in the Quality Control Group more because of economics than anything else, as the desire is to have in-process inspection a responsibility of manufacturing and final inspection in the quality area. Two groups, in our size organization, would be an expensive duplication. Therefore, both are in the Technical area with the one acting as a service group to Manufacturing.

ROLE OF THE QUALITY FUNCTION IN THE MARKETING EFFORT

The Sales and Marketing people must know the capabilities of the manufacturing group. What tolerances are reasonable and what will be the affect, if any, if these can be changed in either direction must be known before a quotation can be developed. This data can be readily obtained from Quality Control capability studies or from inspection data. The Quality Control people can and must thoroughly review all specifications prior to quotation and realistically evaluate the company's ability to meet them. Special emphasis must be given to a review of the test procedures that are to be used. If tests are not available or several test procedures are applicable, resolution of the procedure to be used must be required. Too much pessimism can be dangerous for this can lose an order by taking exceptions that competition can meet. Over optimism can be equally as dangerous.

Actual sales calls by Quality Control people can be a decided asset, especially when they cover such constructive areas as test procedures, possible exchange of standards, preproduction exchange of test samples and review of certification or other documentation that may be required. The simple presentation of test procedures and a discussion of the quality control systems has been a valuable sales tool.

During the term of an order, quality personnel must keep abreast of the incoming inspection status of orders and must aid in cleaning up of any quality problems immediately. A good rapport between quality people in both companies can be beneficial.

One danger that should be emphasized is that no commitment which involves money or delivery should be made by anyone but Sales personnel speaking to Purchasing people, or utter chaos can ensue with a probable high cost to one or both parties. Any change in quality procedures of any kind must be reviewed for their financial implications and properly documented.

Quality personnel should be sales oriented, especially in the manner in which they conduct themselves during visits by customer personnel. Sometimes customer representatives may be in the plant for long periods of time and a relationship with them must be developed for the benefit of both parties. Work on industrywide committees is still one more role that quality people can carry out which has sales overtones.

ROLE OF THE MARKETING PERSONNEL IN THE QUALITY FUNCTION

One of the most important functions that Sales can do for the quality effort is to make sure there is good communications from the customer to appropriate Quality Control people as soon as practical. In addition, they must not abdicate their role as the prime contact with the customer and thus be fully aware of any and all communications between both companies. Sales must establish the exact customer requirements and should be conversant with the procedures used to test the product in both their own and the customer's plant. At times Sales will have to act in a quality capacity because they are actually physically present at the customer's plant when a problem arises or on which they have been called to review material.

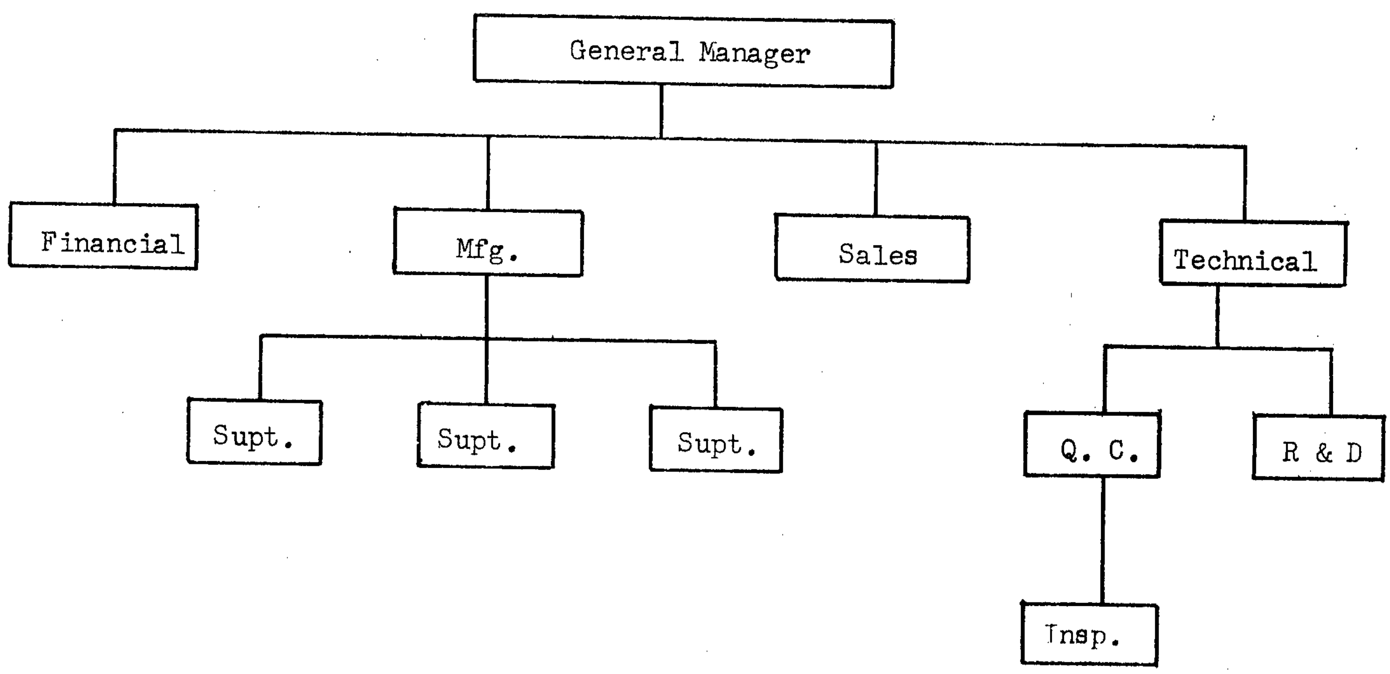
Sales must take an active role in visits by customer quality personnel. This role is sometimes passed along to quality personnel with no liaison with Sales. All customer personnel should come in the plant through Sales and check out with Sales to avoid a multitude of problems.

Finally, probably their most important role can be the neutral judge or arbitrator on behalf of both the customer and the company in any dispute between Quality Control and Manufacturing. Who can best be the judge of what should or should not go to the customer in the never ending grey area of specifications? Normally, Manufacturing would like to ship as much as they can as soon as possible. If some material is not obviously very poor, there is always pressure to ship to the customer. Quality personnel normally would like to see all marginal material rejected or reworked so that there will be little question on the quality level of the product received by the customer. In this situation, Sales comes on the scene. The customer probably needs the material immediately and therefore Sales would like to see the shipment made. However, because they also will be the first to receive any complaints, which could jeopardize needed future business, this group can take a more neutral position than either Quality Control or Manufacturing. Obviously, this is not a role Sales envies but they can be very effective for the benefit of both the

company and the customer if this function is carried out wisely.

CONCLUSION

The Marketing and Sales function has definite and important duties in the overall quality assurance system of a company. Some of their most important roles have been discussed briefly. In turn, the quality people have a vital role to play in the sales effort and some of these duties have also been discussed.



VALUE ENGINEERING IN INSPECTION

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N69-36729

SUMMARY: The use of Value Engineering offers a tool for accomplishing tasks at a lower cost without degradation of quality or reliability. The application of these techniques within the quality organization is discussed, with suggestions as to how the reader may obtain these benefits for himself.

Have you ever felt that some inspection procedure was unreasonable, and therefore, a waste of time when you considered the end use of the item that was being inspected? Of course you have. Perhaps Value Engineering can help you and your company eliminate some of these irritating and profit-consuming experiences.

It has often been said that money talks. By using the data developed by a value engineering study, you can communicate with your management and your customers in a common language, which they will understand. The specialized techniques of Value Engineering are sprinkled with dollar signs. I would like to direct or stimulate your thinking so that you can benefit from Value Engineering in your daily work.

Let us look at the definition of this "value" we are talking about.

VALUE IS THE LEAST COST

FOR AN ESSENTIAL FUNCTION OR SERVICE

AT THE DESIRED TIME AND PLACE

WITH THE REQUIRED QUALITY AND RELIABILITY

It is the search for this value, by knowledgeable individuals, which we call Value Engineering, or possibly, Value Studies, or Value Analysis. To me, the names are synonymous.

Now there is more than one kind of value that we are exposed to in our everyday lives. First, there is "use" value, which is a monetary measure of the propertie or qualities which accomplish the use, work, or service. This is the value which we consider basic. Then, there is "esteem" value which is the monetary measure of

the properties of attractiveness, or of desire to own the item. "Esteem" properties do not necessarily contribute to performance. Finally, there is "exchange" value which is the monetary measure of the properties which we can trade for something that we want. In Value Engineering, we are primarily interested in the "use" value. But, we must remember, that it is a combination of both the "use" value and the "esteem" value, which produce the "exchange" value in the market place.

What we are talking about could be further illustrated by some basic questions which establish Value Engineering's functional approach. Consider a cigarette lighter. The first question, "what is it?"-- a cigarette lighter. The second question, "what does it do?"-- described in two words, it is: lights cigarettes. The third question, "what does it cost?"-- in this case, let us say, $5. Then, in Value Engineering we ask, "what else will do?" Some answers might be: paper matches, wooden matches, a magnifying glass, and flint and steel. What will these items cost? The paper matches are probably free. Wooden matches cost a fractional part of a cent. Let's say an average magnifying glass is worth a half-dollar. A flint and steel is a standard Boy Scout item at approximately a dollar. To supply the basic function of lighting the cigarette, we probably can do this for less than a cent. Therefore, the "use" value of this lighter is approximately one cent, and the "esteem" value of the cigarette lighter accounts for the other $4.99. Perhaps, some of our quality procedures and inspection tools, parallel more nearly the cigarette lighter than the match.

Value Engineering is not cost reduction. Cost reduction concentrates on reducing the cost of the part as it was originally conceived. Nor is Value Engineering work simplification. Work simplification is process-oriented to improve the ways things are done. Value Engineering is function-oriented. Of course, Value Engineering may sometimes use the techniques of both cost reduction and work simplification, but direct them toward obtaining the function at minimum cost.

There is a similarity between Quality Control and Value Engineering in that they are both management tools with which cost as well as reliability can be controlled.

Quality Control assures conformance to design and specifications thereby controlling cost by preventing rejects or substandard performance.

Value Engineering emphasizes conformity to the need behind the customer's design and specifications. Value Engineering can prevent paying for functions which add no significant advantage and may pile on high costs and complexities.

This afternoon we are concerned with how value studies can be applied to quality functions. We certainly have a few things working for us, to ease the introduction of Value Engineering into quality procedures. First, quality personnel have developed certain commendable traits, foremost of which is a questioning attitude. This questioning attitude can be directed toward identifying unnecessary costs which result from some of the following causes:

QUALITY OVER-SPECIFICATION

"NICE-TO-HAVE" INSPECTION DATA

REDUNDANT INSPECTIONS

COSTLY INSPECTION FROM OVERDESIGN

To make it easier to spot these unnecessary costs, without a detailed review of the inspection records, the following test for value may be applied:

DOES THE INSPECTION CONTRIBUTE VALUE?

IS THE INSPECTION COST PROPORTIONATE TO ITS USEFULNESS?

DOES THE Q.C. PROCEDURE NEED ALL OF ITS FEATURES?

CAN IT BE INSPECTED BY A LOWER COST METHOD?

CONSIDERING THE QUANTITIES USED, COULD A LESS COSTLY METHOD BE USED?

DOES INSPECTION COST EXCEED PART COST?

CAN SOMEONE ELSE INSPECT IT AT LESS COST WITHOUT AFFECTING DEPENDABILITY?

TAKE A LOOK AT THE DESIGN ITSELF

An example of quality control capabilities to accumulate and analyze data occurred recently when one of our inspectors in the Quality Test Labs was performing shelf life and strength tests on rolls of adhesives. Sheets of these adhesives are used to bond together the various parts of a helicopter rotor blade by assembling the adhesive between the many parts. Then placing the assembly in an autoclave, the curing is obtained with heat and pressure to complete the assembly. This adhesive has a limited shelf life of approximately five days at room temperature. However, keeping the adhesive refrigerated to below zero, extends the life some 30 times. The original test procedure required removal of the roll from its cold box, allowing it to reach room temperature, and then cutting off samples, which were tested for both flow and strength. However, the inspector realized that he was degrading the shelf life when the roll was warmed to room temperature for samples. The test procedure violated the basic function "insure quality". Investigation disclosed that the supplier's final production control tests could be upgraded to a mutually agreeable standard. We then certified the supplier's test personnel and purchased the adhesive on certification. This is a case of someone else doing it for less. Reduction of incoming tests from 100% to 3% saved approximately $12,000 during the first year. Plus, the elimination of cycling the adhesive roll to room temperature prevented its degradation during a quality check.

A similar study at another company of receiving test requirements for glass roving yielded somewhat similar results. Here resin impregrenated rovings of fiber glass were purchased for use in winding Polaris first-stage rocket chambers. The material was accepted by an attribute sampling plan, MIL-STD-105, which required 33 samples for each lot. A review of one year's receiving history indicated that variable testing would have assured the quality with about the same risk. Therefore, a shift was made to MIL-STD-414 which required only

20 samples per lot, thereby saving, $92,000 of test time during the next two years. Here we have an example of a less costly method of sampling.

One of our very high reliability products is the positive expulsion tank used to supply propellants to maneuvering rockets on space craft. Gas pressure on the outside of a bladder squeezes the liquid out of the tank without the aid of nonexistent gravity forces.

A Value Engineering Study was made to discover why assembly costs on the positive expulsion tanks were high.

The quality member of the team reviewed all the test data on the diffuser tube weld. When the weld leaked, disassembly and rework with a new bladder was required.

It was found that the weld was first checked with N_2 gas pressure while submerged. This N_2 gas test was not as rigorous as the final assembly test made by a helium sniffer.

A helium test was substituted for the less stringent N_2 gas test. Now that first and second tests are alike, no re-work has occurred for this cause in the last two years.

Here asking the question "does the inspection contribute value?" created a first-year savings of $22,524 on re-work parts and labor.

We find that inspectors have a total lack of shyness in pointing out areas of substandard performance, either by man, machine or the system. This also helps us select work areas where improved value will show the maximum yield. For example, it became apparent to an inspector servicing a turret lathe that my company could not economically manufacture this T-bolt, which we machined from a flat bar. The input from the inspector touched off a value study which took a look at the design itself. A survey by Purchasing of both outside machining sources and the availability of purchased parts, resulted in the purchasing a standard forged part to meet the requirement. Savings amounted to 92% on the first year's supply of 250 bolts.

A strong reason for introducing Value Engineering into the quality picture, is to combat the ever increasing sophistication of inspection tools, procedures and processes. An example of a sophisticated inspection set-up is a measuring machine which gives direct reading of axial locations. Air bearings on the slides and probes measure the angle of discharge from the thruster engines on a maneuverable warhead of an intercontinental ballistic missile. The angles of discharge of the thruster engines control pitch, yaw and roll which in essence steers the missile in flight. The six-axis coordinate measuring system probes each of the nozzles exit cones to establish the angle of discharge in relation to specification requirements. While this machine is a significant advance over inspection with height gage and angle plate, studies of the design developed three value increasing changes: (1) A quick method for checking the measuring system; (2) A direct angular error readout without use of conversion tables; and (3) A reposition of table and console to increase operator efficiency. It is interesting that these changes increased the machine's cost, but reduced the overall cost of inspection. These added costs will be recovered as savings of

inspection time during the first 2% of the machine anticipated work load.

We could also recite numerous hardware-type Value Engineering projects which ended in changing the hardware or manufacturing processes due to input from the quality group. But the point that I wish to make is that by coupling the inquiring mind of the quality organization, to the techniques of Value Engineering, increased value can be obtained.

What should you do Monday morning to start the value control ball rolling in the quality organization?

If you are fortunate enough to have a group of Value Engineers, talk with them. They can introduce you to Value Engineering methods, sharpen your inquiring techniques, and add the concept of value to the solution of some of your daily problems.

There are many ways to benefit from Value Engineering. The best results usually are directly proportional to skill in following the value plan, or organized approach, which has five phases:

INFORMATION PHASE

OBJECT: DEFINE FUNCTIONAL REQUIREMENTS

HOW: IDENTIFY PARTS AND USE ESTABLISHED FUNCTIONS
ANALYZE COSTS
STATE THE PROBLEM
"GET ALL THE FACTS"

CREATIVE PHASE

OBJECT: CREATE ALTERNATIVES

HOW: BLAST
BRAINSTORM
SIMPLIFY
ELIMINATE
"NO JUDGMENT YET"

EVALUATION PHASE

OBJECT: SELECT BETTER IDEAS

HOW: REFINE
COMBINE
DISCARD
TRY R.O.M. $
"USE GOOD BUSINESS JUDGMENT"

INVESTIGATION PHASE

OBJECT: SELECT BEST IDEA

HOW: DEVELOP APPROACH
PLAN FOR ACCEPTANCE
RECOGNIZE ALTERNATES
CONSULT EXPERTS
"CHANGE NOT, FOR CHANGES SAKE"

RECOMMENDATION PHASE

OBJECT: IMPLEMENT VALUE PROPOSAL

HOW: COMPARE COSTS
SPECIFIC ADVANTAGES
DEFINE IMPLEMENTING PROGRAM
ANTICIPATE PROBLEMS
"RESULTS -- SAVINGS"

This plan looks deceptively simple, but only the strong individual can follow it alone. Team effort is usually best, with one or more members firmly grounded in the value techniques to keep the team on the track. You also need management support, both to obtain team members and also to give impetus in adopting cost savings ideas. After you have the training and management support, you need goals of dollar value and time. A general goal would be to save $10 for every dollar spent in search for better value. At Bell Aerosystems Company, for example, we also have a yearly goal to save one million dollars. These goals help create management support and give direction to each value team's effort.

I'm sure your value team will find information gathering an interesting and demanding chore. The creative phase will be stimulating and rewarding. The evaluation phase will be an interesting exercise in self expression. But from here on in, you may be in trouble. Detailed investigation and planning is less fun. Doubts begin on how the recommendations should be presented and how they will be received. But your presentation to management for approval must define implementation or you will never realize savings. Management acceptance of your savings recommendation will be an indication that the original project was well selected; the techniques were well used; and the solution was well supported.

Well, that's what you must do to add Value Engineering to your profession.

I wish you success in value control of your inspection efforts.

HOW GOOD ARE YOUR GAGES?

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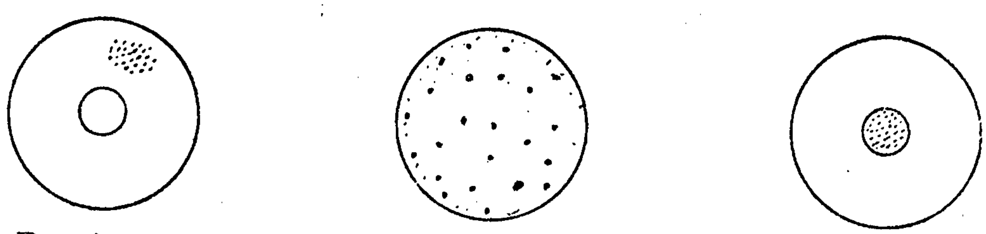
N69-36730

This paper deals with a simple, yet effective technique for evaluating measurement type gages and measurement systems. This technique was presented by a General Electric Engineer at the 1962 National ASQC Convention. Subsequent to that, many versions of this technique have been published, but usage of the technique has been very limited.

As an introduction to this presentation, let's define some terms such as precise, accurate, repeatability, reproducibility, stability, and overall accuracy.

Precise and accurate can best be defined with the use of the bull's-eye sketch.



Precise but Not Accurate — Accurate but Not Precise — Precise/Accurate

Repeatability is defined as the variation in measurements obtained by one individual, measuring the same characteristic several times using the same gage or measurement system.

Reproducibility is defined as the variation (difference) in the averages of a group of identical measurements made by two different people using the same measurement system.

Stability is defined as the variation (difference) of averages in the measurements taken by an instrument as a result of time.

Overall Accuracy is defined as the total evaluation of accuracy, repeatability, reproducibility and stability.

A gage is said to have sufficient accuracy if the degree of readable divisions within the blue print tolerance is a factor of 10. For example, if the total tolerance is .001, the gage should be readable to .0001. Readable does not mean accurate or precise. This technique makes it possible to determine the accuracy/precision of the gages as well as the effectiveness of the gage system.

Inspection planning is not only the function of where to inspect, but how to inspect, and what to inspect with. Data aquisition is extremely important for a good functional analysis, but the data has to be good before a good analysis can be performed.

To implement this technique, the following considerations must be established:

1) Why is the study being made? Define the problem.

2) What type of information is needed? Data?

3) What procedure is to be followed to collect data?

4) What influence has the operator to the gage system?

5) Who is to make the measurements?

6) How many measurements are to be made?

7) The type of gage to be analyzed must be of the direct reading type such as a dial indicator and not gages such as plug gages.

8) In cases where physical parts are not available and must be substituted with a gage block, standard resistor or some form of a "master", random repetitive readings are to be taken by the operator(s) and analyzed using the moving range method. More on this phase of the technique will be discussed later.

Once the above (8) considerations have been taken into account, the basic study can be started. The steps to complete the form are fairly simple. However, remember, the study will only be as good as the data collected.

1) Data to be taken in a random order to insure any drift or changes that could occur will be randomly

distributed throughout the study.

2) The study should be observed by an engineer who is familiar with the technical aspects of the equipment being studied.

3) As a suggestion in running a study of this type, the form given as an example in the appendix of this paper, is provided.

The "magic" numbers that appear on the form are developed by the following method:

3.268 is the D_4 factor for ranges of two which is a standard table value.

4.564 $\overline{R}$ is developed as the estimate of the spread using the range of two readings. The specific values are average range ($\overline{R}$) divided by d_2 factor for ranges of 2 (1.128) multiplied by 2 times the Z table value of 49.5% to obtain 99% spread 2 x 2.575. In equation form

$$\frac{\overline{R}}{d_2} \times 2 \times 2.575 = 4.564\ \overline{R}$$

Depending on the amount of spread desired, the constant of 2.575 may be substituted for. For example:

95% limits	Constant is 1.96
6 σ limits	Constant is 3.00

Collecting the data should be in accordance with the following recommendations:

1) Number the individual parts to be measured.

2) Have Inspector #A measure the parts at random telling the observing engineer what values to record in the first column. (A-1).

3) Have Inspector #B measure the parts at random without knowing the results of Inspector #A and record the values in Column 1 (B-1) in the same manner as Step 2.

4) Repeat Steps 2 and 3 for the remaining two columns. The inspectors, for all measurements, utilize the same gage and lot of parts.

The analysis of the data is performed in the following manner:

1) Take the absolute difference between Columns 1 and 2 for each inspector and enter the result as a positive number in the respective difference columns.

2) Total all columns and enter values in respective blank.

3) From the totals, determine the respective averages and record in the average blanks.

4) Enter the average of Column 1 to the appropriate blank under Column 2, sum the two values and divide by two to determine the respective averages.

5) Transfer the average ranges and the averages calculated by Step 4, to the respective blocks.

6) Sum the two ranges and divide by two to determine the grand average range.

7) Using the value of Step 6, calculate the upper control limit of the range by multiplying by 3.268. Compare this figure to each of the figures in each difference column. If any individual readings exceed the control limit, discard the data for that piece and recompute all necessary factors. Perform this step until all difference values are equal to or less than the calculated control limit.

8) Another method of trying to produce differences within the limits of Step 7 is to remeasure the same part with the same gage and inspector.

9) The repeatability of the gage is determined by multiplying the value of Step 6 (grand average range) by the factor 456.4 (4.564 x 100%) divided by the total blue print tolerance. The resultant figure is the total per cent of the part tolerance consumed by gage error.

10) Reproducibility is determined by multiplying the difference of the averages by 100% and dividing by the blue print tolerance. This figure represents the total per cent of the tolerance consumed by inspector differences in gage usage.

11) The total measurement system error, expressed as a per cent of drawing tolerance consumed is determined by the summation of the repeatability and reproducibility.

Now that we've shown how to evaluate the gage system, what are the limits that would make a system defective and what can be done to correct the system?

As far as the limits, it is up to the specific requirements of the part or process and the respective consumer to determine what is acceptable. Normally, uncertainties up to 20% are considered acceptable. However, some military requirements may be as low as 5%.

To correct a defective gage system may be extremely difficult because of costs, state-of-the-art, equipment availability, and other factors too numerous to mention. Tool engineering, inspection planning or whatever a company calls the responsible design and fabrication area of gages, should be notified when a gage system is defective to determine what should or can be done.

Other methods of reducing variation of a gage would be to take several readings and use the average. This variation is reduced by a factor of 1 divided by the square root of "N" readings.

This technique is very effective in evaluating any mechanical, electrical, electronic or any other type of quality information equipment that generates a specific numeric measurement. This procedure can be utilized by Quality people involved in vendor analysis, (equipment suppliers), or any evaluations of suspect gage equipment utilized for capability analysis.

PROJECT ________________

DATE ________

GAGE NO. ________

DWG. TOL. ________

	Oper. A			Oper. B		
Pc No.	1	2	Diff.	1	2	Diff.
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Total						
Avg.						

Sum.		R_A↑	Sum.	
Total			Total	
$\bar{x}_A$ Avg.			$\bar{x}_B$ Avg.	

R_B↑

R_A	
R_B	
Total	
$\bar{R}$	

$UCL_R = \bar{R}$ ________ x 3.268 = ________

Repeatability

$\bar{R}$ ________ x456.4 ÷ ________ B/p Tol.= ________ %

Reproducibility

X_A	
X_B	
Diff.	

$\bar{x}$ Diff. ________ x 100 ÷ ________ B/p Tol.= ________ %

Total System Error = Repeatability + Reproducibility.

________ % + ________ % = ________ % Total Gage & Operator Consumes Of Dwg. Tol.

OPERATIONAL HISTORY AND EXPERIENCE WITH THE BELL SK-5 AIR CUSHION VEHICLE (ACV)

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SUMMARY:

The active participation of the air cushion vehicle in the Vietnam war has produced an opportunity to evaluate a limited number of ACV's (6 total craft) under the most rigorous and extreme environmental and combat conditions.

This paper presents a brief resume of experience of Bell SK-5 ACV's as related to operations in Vietnam since the deployment of the first three Patrol ACV's (PACV's) by the U. S. Navy in 1966 and U. S. Army ACV's in 1968. Specifically, the roles and growth of the SK-5 are discussed.

Introduction of a new and unique vehicle which was originally designed for commercial applications into a military environment has necessitated the development of unique measures for assessing the reliability and maintainability of these crafts. This paper presents some of the results of this assessment in terms of operational readiness and other system effectiveness indices.

SERVICE LIFE PREDICTIONS

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SUMMARY: This paper presents a method for predicting the service life of a system. Procedures for identifying and testing system variables for both operational and non-operational phases of a mission are discussed. Statistical techniques for obtaining service life estimates from variables test data are outlined and the predicted service life of the system is observed to be the shortest of the service life estimates for the family of variables.

INTRODUCTION

In recent years, increasing attention has been given to the probable effects of long service intervals on the performance of complex systems.[1,6] Interest has been centered primarily on long range ballistic missiles which are deployed in permanent underground structures in a state of full operational readiness. This state of readiness requires that the missiles be fueled and in firing position for extensive service periods.[2] Since the missiles must be capable of functioning within definite limits of performance when called upon, and of meeting quantitative reliability goals, needs have arisen to identify and eliminate effects which tend to restrict these capabilities.[3] These effects include metal corrosion, propellant leakage, material creep, and deterioration of electrical, mechanical, and chemical properties. The study of these effects has also introduced a new design constraint, namely: the length of time a system can remain in service and still perform the functions for which it was designed. This time interval will be referred to as the service life of the system, and a method for predicting the service life of a type system will be the subject of this paper.

METHOD

The method of predicting service life is conceived to be a four step approach as follows:

1) Define the system, its service environment and mission.

2) Identify the variables for the system and identify the environmental factors which could degrade them. Calculate the limiting values of the variables for mission success.

3) Establish testing programs to measure changes in these variables as a function of time.

4) Obtain statistical estimates (from the test data) of the true regression on time for each variable. The shortest time to achieve intersection of the regression estimates and their respective limiting values yields the service life of the system.

DEFINING THE SYSTEM

As a first step, the system must be thoroughly defined and its limitations understood. We must have a clear idea of the type of environment to which the system will be exposed while in service and the length of time it is expected to remain in service. The system functions to be performed must be clearly defined and the mission objectives for which these functions are performed must be stated.

IDENTIFYING VARIABLES

The second step is somewhat more detailed. We must identify all of the variables by which the system can possibly fail. There are those variables which express the performance of a system, examples of which are engine thrust and specific impulse. Another group of variables may express the status of the system during non-operational periods. Examples of status variables are gas storage pressure, and stored propellant quantity. A third type of variable comprises the general grouping of variables which are undetectable at the system level but which are intrinsically related to both the performance and status variables. An example of an undetectable variable is the amount of deformation in free length that can be tolerated for a regulator spring before the regulated pressure (a performance variable) falls below an acceptable level. The deformation of the spring is an undetectable variable because it cannot be instrumented for pickup as a performance variable, nor can it be measured as a status variable during system "on-line" checkout. Other examples of undetectable variables are the yielding properties of structural materials, the explosive properties of pyrotechnic compounds and the constituency of stored propellants.

Along with identifying all of the variables by which the system can fail we must identify all of the environmental factors which could possibly influence the behavior of these variables. These factors include time of service (both operational and non-operational), temperature, pressure, altitude, humidity, vibration mode, and any other environmental factor which is deemed pertinent. The ultimate objective is to express each of the variables as a function of service time since this is the only practical way in which service life estimates can be obtained. If however, the system is exposed to extremes of environment such that factors other than

service time tend to influence a given variable it may be necessary to express that variable as a function of service time for several levels of the factor in question. For example, if gas storage pressure, a status variable, is significantly different at 60°F than at 100°F, and these temperature extremes prevail for the service environment, it would then be necessary to express the gas storage pressure as a function of service time at both 60°F and at 100°F.

Another necessary adjunct to identifying variables is to calculate the limiting values of each variable which can be tolerated. We will call these limiting values "failure criteria". The failure criterion for a particular variable is that value beyond which failure of the system mission can occur. The computation of these values usually involves computer simulation techniques and parametric studies which express "worstcase" values of the variables. Typical failure criteria for a hypothetical propulsion system are depicted in Table I. Let us assume, for discussion purposes, that the table presents typical variables for a propulsion system which is required to be stored within an atmospherically controlled environment for 5 years, and that the system is fully pressurized and loaded with propellants, in order to perform a given mission on command.[7] The status variables express the criteria for satisfactory readout of the system during its storage period, while the performance variables indicate the failure criteria for a successful mission should the system be actuated during the 5 year interval. The undetectable variables express the criteria for failure during either the storage period or the mission.

THE TESTING PROGRAM

Having identified the variables by which an operational system may fail during its period of service, our next step is to consider how we could test a given number of systems to demonstrate that the system will perform adequately throughout the service period. The basic considerations in planning a test program include:

1) The value of a given variable for any given time interval of system deployment (in the service environment) should be observed independently of any other interval of deployment. That is, the tests should be designed in such a manner that one system will be deployed for one interval and tested. A second system will be deployed for a longer period and tested, a third system will be deployed for a still longer period and tested, and so on until a given quantity of systems, each representing a progressively longer interval of deployment are tested. This will yield a number of independent observations of each variable in time. If factors other than time are likely to influence the test data such as tem-

perature, pressure, or humidity, independent measurements for various levels of the factor in question must also be taken along with those for time. In the example of Table 1, only time is a factor since the service environment is assumed to be controlled.

2) Facilities must be available to simulate the service environment for deployment of the system complete with instrumentation to provide the necessary status readouts. Facilities to simulate the flight conditions under which the system must operate must also be provided along with instrumentation. In our example, an altitude chamber with vibration apparatus must be provided to simulate flight and an atmospherically controlled storage facility must be provided to simulate the storage environment.

3) To provide a means of measuring those variables which cannot be picked up by instrumentation during the system readiness and flight phases of the mission, a laboratory support program should be included in the test planning. For example, for our hypothetical system, relaxation of the main spring in the regulator component can best be evaluated by a laboratory program which duplicates the system load conditions on the spring by means of special devices. Yield point data for the gas storage tank material, explosive pressure thermal conductivity, and analyses of propellants also fall into the laboratory support category. In general, those variables which express the effects of the service environment but which are undetectable through system instrumentation will be included in a laboratory support program. Independent time observations for laboratory details should of course, correspond to those selected for systems in order to provide common data. Consideration should also be given to disassembly and retesting of system components after full scale system tests in order to provide additional observations with no added expenditure in hardware.

STATISTICAL ANALYSIS OF DATA

The final step in the prediction of service life is to establish statistical techniques which will relate failure criteria to estimates of the true regression on time for each variable.

We have made a very fundamental assertion by making the above statement and that is that time is the single factor that will cause changes in each of the variables. Stated another way, we have said that each variable will be expressed as a monotone function of time. This may, or may not be the case depending on the service environment and careful thought must be given in designing the experiment to assure that the monotone relationship is sound. For example, if we had a service environment in which the conditions were not ambient

but varied between considerable extremes, it might be necessary to consider each variable as a multiple regression on several independent variables, including time. Each independent variable, or factor, would then be tested for significance, and if significance were found, the regression model would have to be reconstructed as a monotone function of time for particular levels of the factor in question. If no significance were found for factors other than time, the effects of these factors could be ignored and grouped as constants under the Y-intercept term of the regression equation. The ultimate objective of course, is to be able to express each of the performance, status, and undetectable variables as independent regressions of these variables on time. If we can accomplish this, we have the means for predicting the service life of the system.

The reader is referred to several excellent texts in the bibliography[8,9] for statistical background concerning multiple regression techniques, both linear and non-linear. For the purpose of this paper we will merely itemize the statistical procedure involved in predicting service life and leave it to the reader to pursue the subject in more detail.

1) Each of the variables should be measured at independent, successive time intervals to observe changes with time. As data is accumulated for successive periods, estimates of the true regression on time will be made for each variable after the necessary significance tests have been made as stated above.

2) The "best fit estimate" will be plotted and the prediction interval for individual values of each variable will be calculated and superimposed on the regression plot.

3) The failure criterion for each variable will be superimposed on the regression plot for that variable. The intersection of the failure criterion and prediction interval will be the estimated service life. The <u>shortest of these service life indications will be the maximum predicted service life of the system.</u>

Figure 1 shows hypothetical regression plots for each of the variables of Table 1. From this we see that intersection of the prediction interval and failure criterion is achieved earliest for the regulated outlet pressure variable and is shown to be four years. Hence this is the maximum expected service life of the system. To be deployed for the necessary 5 years, the system of this example would either require maintenance and replacement of the regulator component after 4 years, or redesign of the system to achieve the necessary 5 year service life without maintenance.

SUMMARY

This paper presented a method for predicting service life based on known technology and known statistical theory. It was not an attempt to "sell"

a new discipline although the author personally feels that ultimately the prediction of service life can take its place alongside such proven disciplines as reliability and maintainability. The test, after all, of any design discipline is whether or not that discipline will prove effective in achieving specific design goals, whatever they may be. There is little doubt that service life programs (or surveillance programs as they have come to be known) have been effective in estimating accurately the service life of systems and components.[4] However, these estimates are all too often of academic interest only, since by the time an accurate estimate of service life is rendered, the development program and even the production program may have phased out. Sometimes even the need for a particular design may have ended, so that the requirement to learn its service life is superficial to say the least. Even in areas where surveillance programs have received their greatest impetus, namely the stored ballistic missiles field, the development effort has not always coincided with needs. Perhaps the biggest single drawback of these programs is that they are not integrated with regular R&D programs on an equal basis with reliability and maintainability. In the typical R&D program for example, reliability and maintainability tests are part of the design verification phase of the contract and a tradeoff is made with these test results in mind. There are logical arguments for integrating surveillance tests with the R&D effort by extrapolating long term results from short term data, but little evidence to suggest that this is being seriously considered. It is hoped that this presentation may spur some effort in this direction.

Group I Operational (Performance) Variables	Failure Criterion
1. Engine specific impulse	1000 seconds (min)
2. Engine Thrust	500 lbs (min)
3. Regulated outlet pressure	184 psia (min)
Group II Non-Operational (Status) Variables	
1. Total usable propellant quantity	100 lbs (min)
2. Gas storage pressure	3000 psia (min)
Group III Undetectable Variables	
1. Pressure tank yield point	30,000 psi (min)
2. Change in explosive pressure	20% (max)
3. Relaxation, regulator spring	21.4% (max)
4. Nitrous oxide concentration, propellant	0.6% (max)
5. Thermal Conductivity (engine liner)	.080 Btu/ft -°F (max)

TABLE 1 HYPOTHETICAL SYSTEM VARIABLES AND LIMITING VALUES FOR MISSION SUCCESS

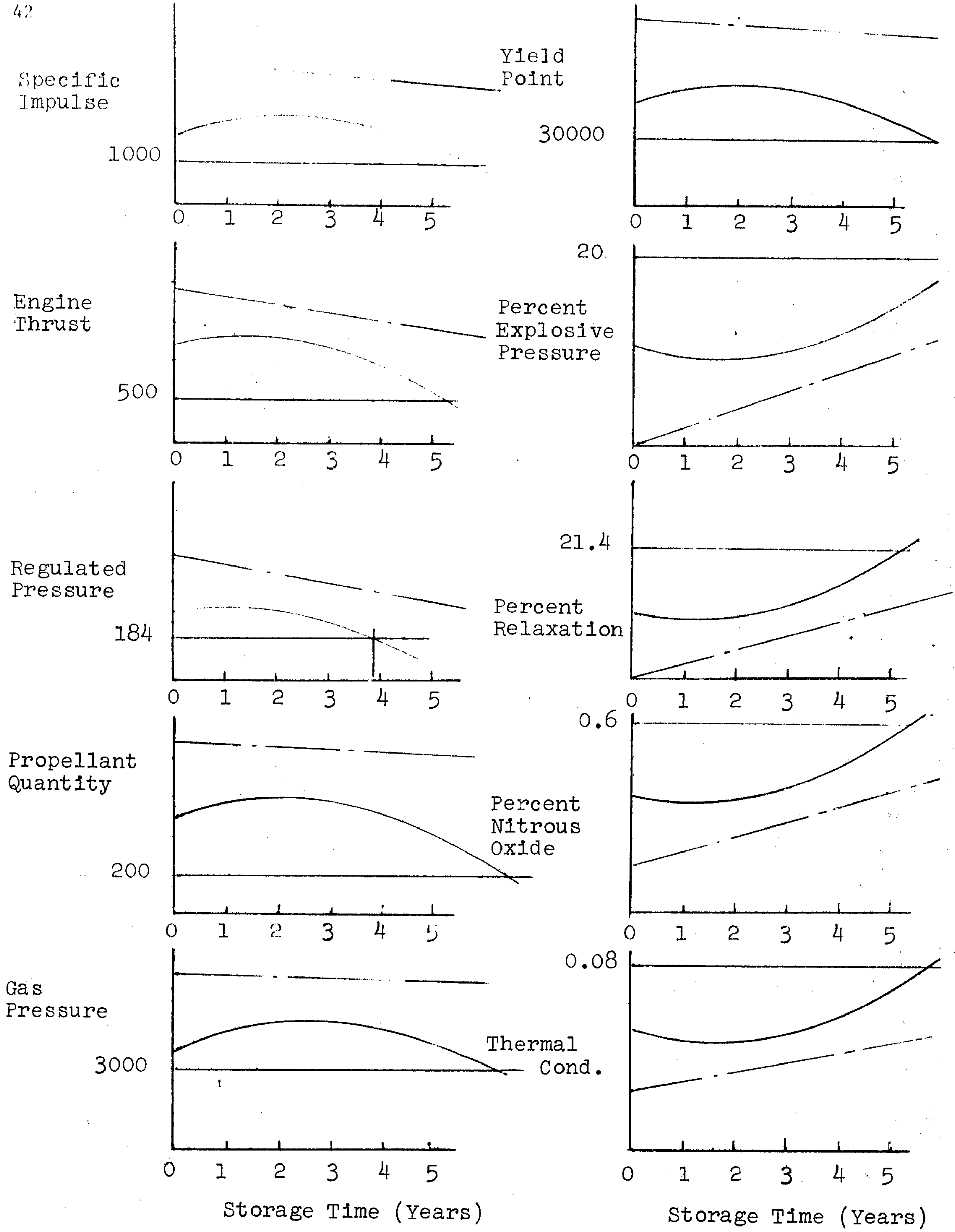

FIGURE 1. HYPOTHETICAL REGRESSION PLOTS

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WHEN DOES QUALITY BECOME RELIABILITY?

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SUMMARY: Reliability Engineering applied to a complex electronics equipment, requires the use of technical and management methods, if the specified reliability is to be achieved.

The reliability program must provide direction to all major functions of the business cycle. Secondarily, use of quantitative data is required to assess the results of these efforts. The assessments, to be effective, must be of a simple and direct form, readily comprehended by production personnel, middle management, and top management.

INTRODUCTION

Given a product on which a guaranteed mean time between failure (MTBF), has been accepted, resulting in a potential high risk and liability to the profits of a company, the resources of the program must be integrated and directed to achieve this objective in consonance with all other requirements.

The field of reliability management is abundant with various statistical connotations. By applying a directed approach to product design and manufacturing, conformance with a specified MTBF during a reliability demonstration test becomes a natural evolution, rather than an unknown high risk application of statistical theory, since only through detailed definition and control can the truism, "reliability must be designed in," be fully realized. The conceptual approach applied through the product discussed in this paper is shown as Figure 1.

BACKGROUND

The product under contract is a system consisting of four black boxes, using state-of-the-art design techniques, in order to achieve a high level of performance. On the order of 2,700 active components (resistors, capacitors, integrated circuits, etc.) were required to attain these performance characteristics. One major provision of this program was a contract specified MTBF of 600 hours. This figure of merit was to be validated on production systems using an AGREE Qualification Test procedure.

This program also contained a provision for production AGREE sampling tests, in order to assess potential degradation to the MTBF with time, as a result of the manufacturing process and any associated design changes.

As a result of the periodic nature of this requirement, the cumulative company risk and cost were a direct function of the production span time. This situation provided a significant inducement, to continually assess results of the design and manufacturing processes against the specified MTBF.

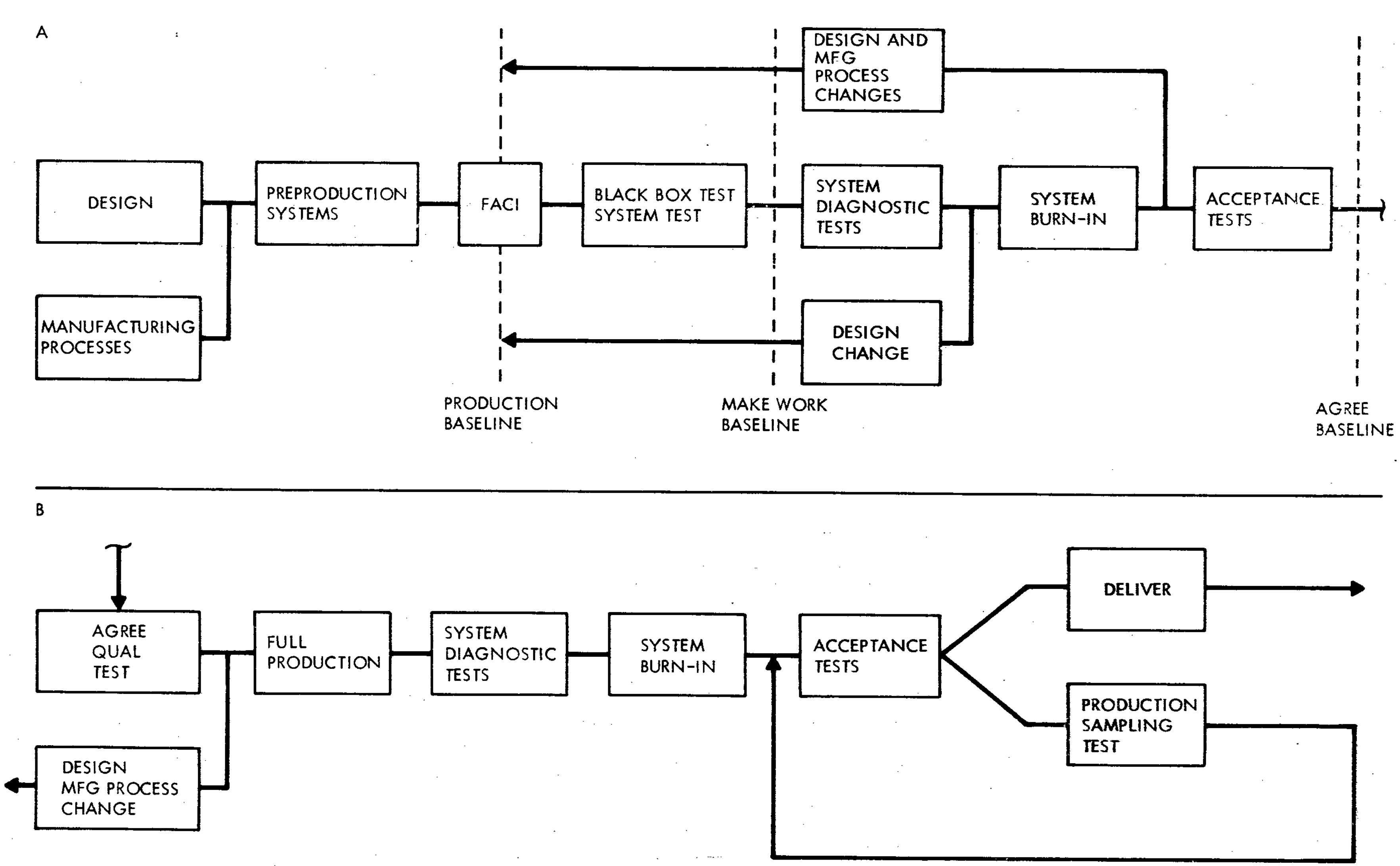

Figure 1. Major Program Elements Conceptual

AGREE TESTING

The Advisory Group on the Reliability of Electronic Equipment (AGREE), issued, in June of 1957, a series of nine tasks which had been developed mutually between industry and government task committees. Task No. 2 was addressed to verification of reliability in design and manufacturing through specific testing procedures. This task was subsequently evolved into MIL-STD-781, "Reliability Tests, Exponential Distribution," which provided a series of test plans utilizing sequential analysis and specifically based on:

a. ultimate environmental usage of the product.

b. specified consumer (β), and producer (α) risks.

c. a ratio of contract specified mean time between failure and a minimum acceptable mean time between failure. This ratio is expressed as a discrimination ratio for purposes of normalizing the test plans of MIL-STD-781.

The requirements associated with the product discussed in this paper were:

a. a contract specified mean time between failure of 600 hours.

b. a producer risk equal to the consumer risk of 10 percent (at truncation).

c. a discrimination ratio of 2.0:1.

d. the validation of the contract specified MTBF to be accomplished under the requirements of Test Level E. The environmental profile of Test Level E is shown in Figure 2.

AGREE QUALIFICATION TEST INITIAL PRODUCTION PHASE

The manner in which the AGREE Qualification Test was to be accomplished was defined as follows:

> Each of the first 16 production systems was to be placed on test for 390 "ON" hours. In order to realize an ACCEPT decision, at the point of truncation, no more than 20 relevant failures were allowed. The relationship of the contract specified MTBF, discrimination ratio, and the consumer/producer risks are shown in the Reliability Operating Characteristic (ROC) Curve on Figure 3.

As a result, 16 x 390 = 6,240 system hours of test were required with no more than 20 relevant failures allowed to achieve an accept decision. Assuming exactly the specified hours and number of relevant failures allowed were realized at the point of truncation (accept decision), an MTBF of 312 hours (point estimate) would result.

$$\text{MTBF} = \frac{16 \text{ sys} \times 390 \text{ hrs/sys}}{20 \text{ failures}} = 312 \text{ hrs}$$

The significance of this value with respect to the subsequent eight production sampling tests will be illustrated later in this paper.

The design of the sequential scheme represented by the ROC Curve of Figure 3 is shown in Figure 4. For purposes of qualification, testing continued to the point of truncation, (6,240 hours). For each production sampling test, the test was to be terminated once a decision line (accept or reject) was crossed. As illustrated in Figure 1, delivery was restricted until an accept decision was reached in the AGREE Qualification Test.

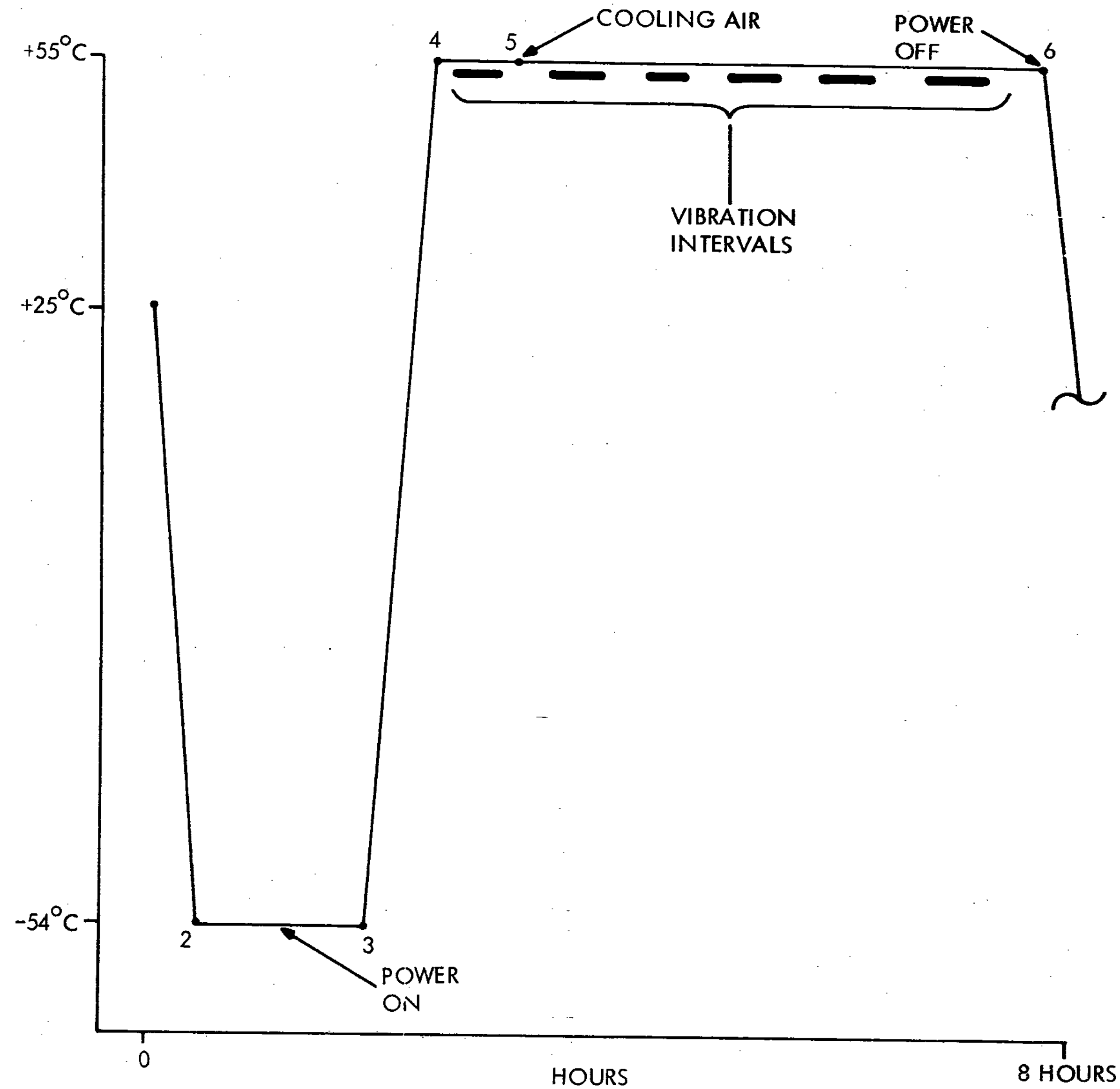

Figure 2. Test Profile

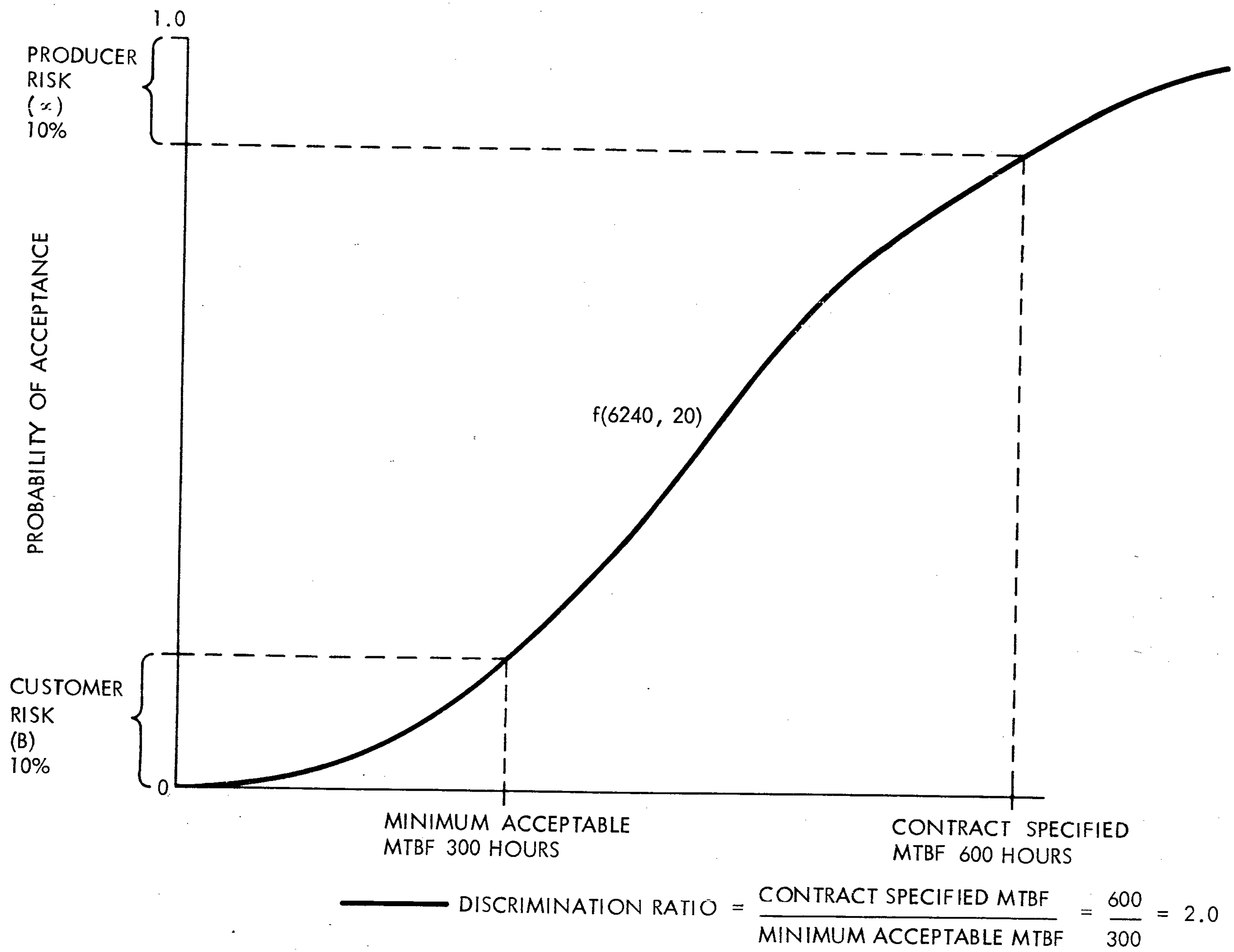

Figure 3. Reliability Operating Characteristic (ROC) Curve-at Truncation

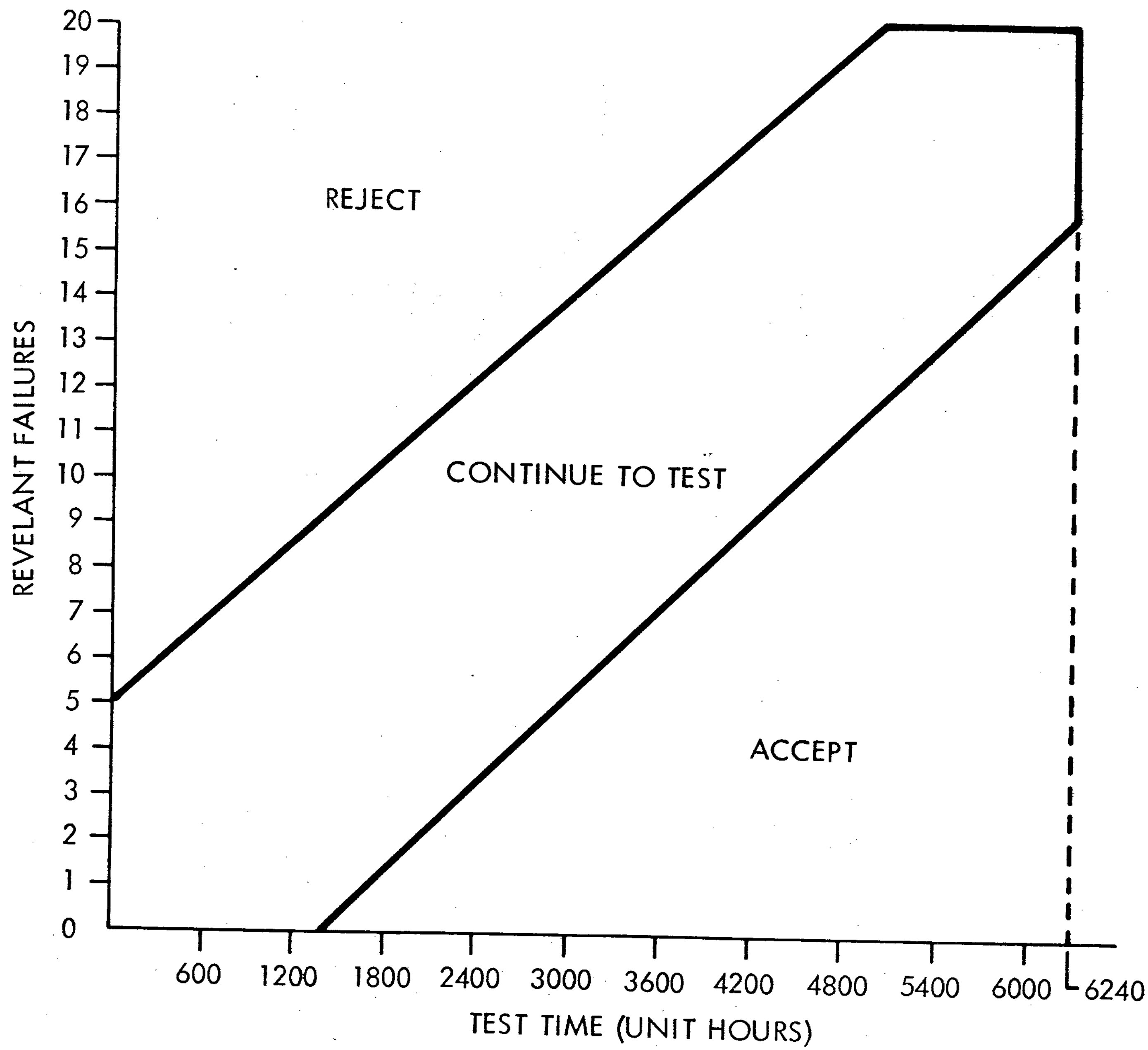

Figure 4. AGREE Sequential Test Plan

Delivery was maintained on a monthly basis after this point, concurrent with the production sampling tests as long as a reject decision was not experienced.

One aspect of the liability associated with this program, was the need for retrofit of all delivered systems and retest should a reject decision be experienced during any one of the production sampling tests.

POTENTIAL MODES OF FAILURE

As previously stated, the product contained 2,700 active components in four black boxes. Therefore, a total part complement of 43,200 components (16 systems x 2,700 parts/system) was to be subjected to the AGREE environment for qualification as well as each of the periodic production samples. A conservative assumption is that each part could have 3 modes of failure. For an example, a resistor can fail open, short, or drift significantly enough to cause circuit, hence, system failure. Multiplying through shows that there are a minimum of 129,600 (3 modes of failure/part x 43,200 parts) potential modes of failure for each AGREE Test. This value is conservative, since the product contained 400 integrated circuits, each of which averaged 15 leads, in addition, all active components contained a minimum of 2 active leads. As a result, there were a high number of lead connections, which through improper soldering or assembly techniques could introduce an additional mechanism of failure which would be additive to the modes of failure associated with each of the active components.

Contribution to Potential Failures-Per System

400 Integrated Circuits x 15 leads x 1 solder joint per lead	= 6,000
2300 Active discrete components x 2 leads x 1 solder joint per lead	= 4,600
TOTAL	10,600

Potential Quantity of Failures Per AGREE Test

16 systems/test x 10,600 connections/system = 169,600

IN-PROCESS TESTING PROGRAMS

In order to provide an extensive data base early in the program, as well as a high degree of confidence in the integrity of the delivered product, an integrated test program was developed. A general flow of the testing program utilized at each indentured level of this product is shown in Figure 5.

As each test level and test need was identified, it was related to the environmental extremes and thermal stresses of the AGREE cycle (Figure 2). Of particular note were the System Diagnostic tests and the System Burn-In tests which were accomplished on all systems prior to delivery. The Diagnostic test was the first exposure of the system to environmental stresses equivalent to that of the AGREE cycle, once black box and System Acceptance tests, at ambient, had been accomplished. The purpose of the Diagnostic tests was to assess design margins with respect to the subsequent AGREE Qualification test and operational environment.

GENERAL FLOW

Component	Vendor	In House
Plug In Boards	Electrical Test	
Printed Circuit Boards	Card Conditioning - 36 Hours Electrical Test	
Modules	Subassembly Electrical Tests Module Electrical Test Module Conditioning - 96 Hours	
Black Box Test	Electrical Test	
System Test	Compatibility	
System Diagnostic Test	Diagnostic Procedure ($-54^\circ C$ - $+55^\circ C$)	
System Burn-In	Burn-In Procedure ($-54^\circ C$ - $+55^\circ C$, 48 Hours ON Time)	

DIAGNOSTIC   BURN-IN

System Troubleshooting Ambient
System Troubleshooting Chamber

Black Box Troubleshooting and Repair
Module
Subassembly
Card
Component

FAILURE ANALYSIS

In House   Vendor

FIGURE 5

The System Burn-In test was implemented to screen or cull-out the maximum percentage of latent faults or workmanship defects of the system which could be classified as "infant mortality" failures. Since the real world situation seldom provides the prerogative to provide a completely debugged design to the manufacturing operation, there were design problems detected during the course of the System Diagnostic and Burn-In tests, which required design and process corrective actions, subsequent AGREE validation and retrofit, during the initial months of production. These actions were incorporated in all production systems to bring the product up to what can be called an "AGREE Baseline."

This test program provided a minimum energized test time on each component prior to AGREE or delivery of 236 hours. This experience is illustrated in Figure 6, and assumes no recycling of material.

QUICK REPAIR CAPABILITY (QRC) OPERATION

Specific directives and procedures were developed and issued to orient the program toward a successful AGREE Qualification test. These directives were necessary to provide the production worker with the visability to identify his function with the AGREE process. The implementation of the directives resulted in a data base expressed quantitatively by percent yield at each test position. Average span time through each test phase of all black box and system tests of all production material was likewise used to assess product quality and reliability.

A typical flow diagram used to process all failures out of each system test (AGREE, Burn-In, Diagnostic, Acceptance) and the Black Box and Module tests is shown as Figure 7.

The flow shown represents the critical elements of the basic material flow, repair, troubleshooting and inspection process established to process an average monthly flow rate to satisfy delivery requirements. Identity of these events are pertinent for progressively assessing program success in the AGREE process by middle management. Average dwell times in each block showed the need for additional personnel, training or test facilities.

Since the first sixteen production units were to be committed to the AGREE Qualification test, there was the need to define, in the production plan, the subsequent build and test of production systems so that once the AGREE Qualification test was complete, they could be supplied to the customer at the required rate. It was therefore, necessary to relate the significance of priorities of production material to the AGREE and Burn-In and Diagnostic failure analysis process, such that management could assess potential risk in terms of slipped schedules.

Projected targets were established using early failures experienced from the System Diagnostic test, System Burn-In test and predicted AGREE experience. Since the testing program was a major constituent of the production process, specific span times were developed based on measured rates of failure,on which the production schedule was predicated. The methodology used to assess contribution by major function on the program (manufacturing, design, and components) against the targets allowed, are summarized on Figure 8.

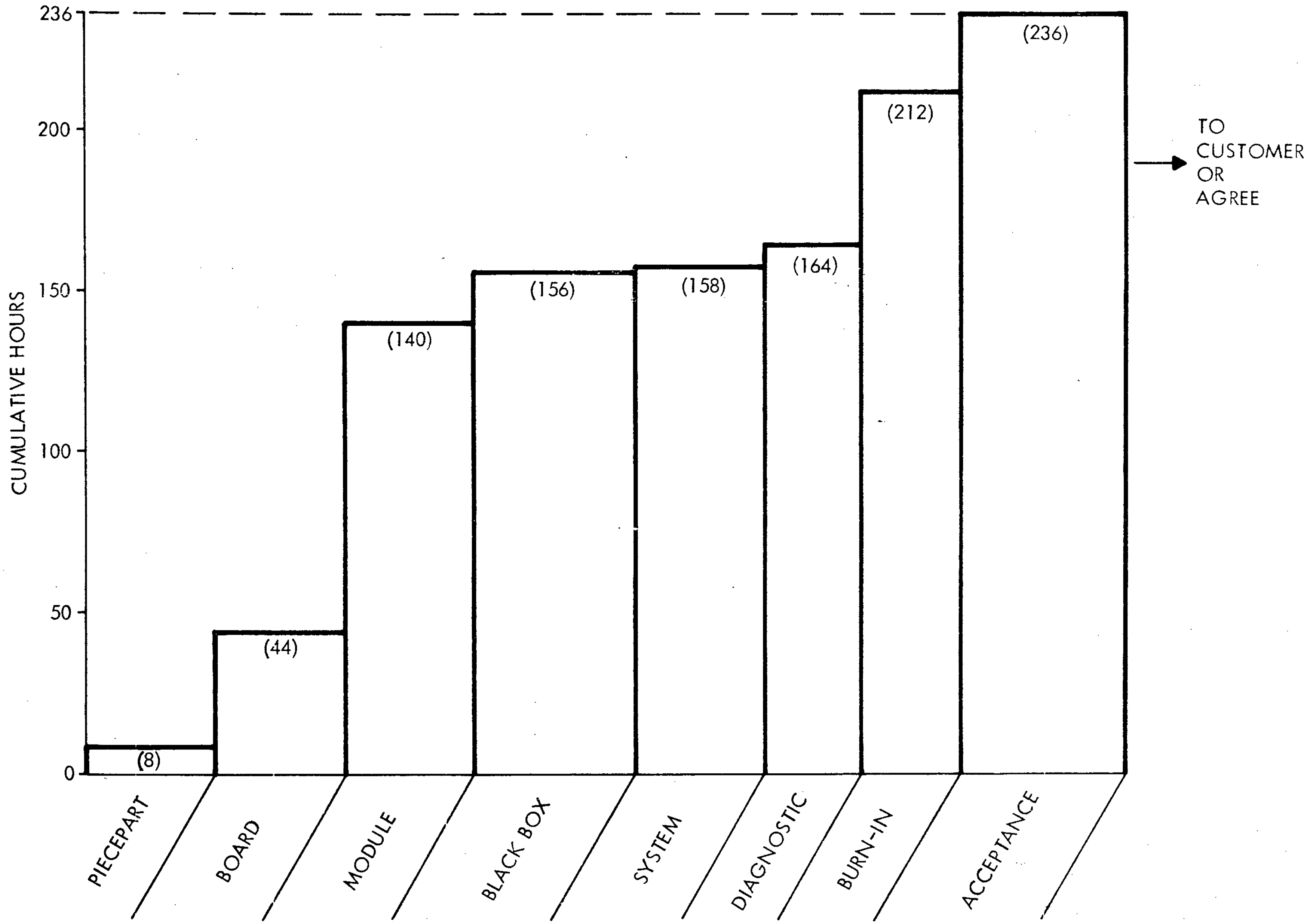

Figure 6. Effective Component Hours

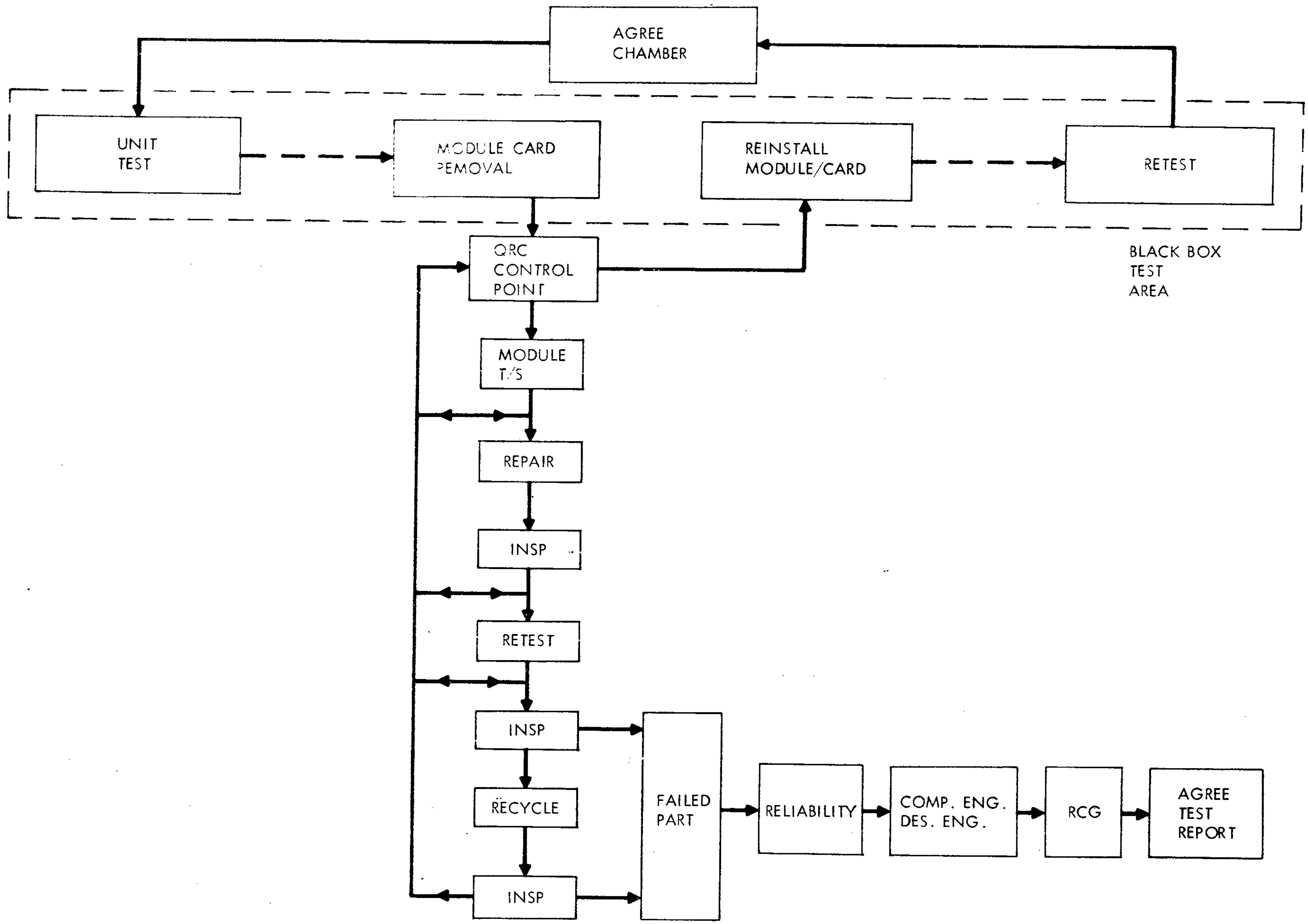

Figure 7. QRC Process

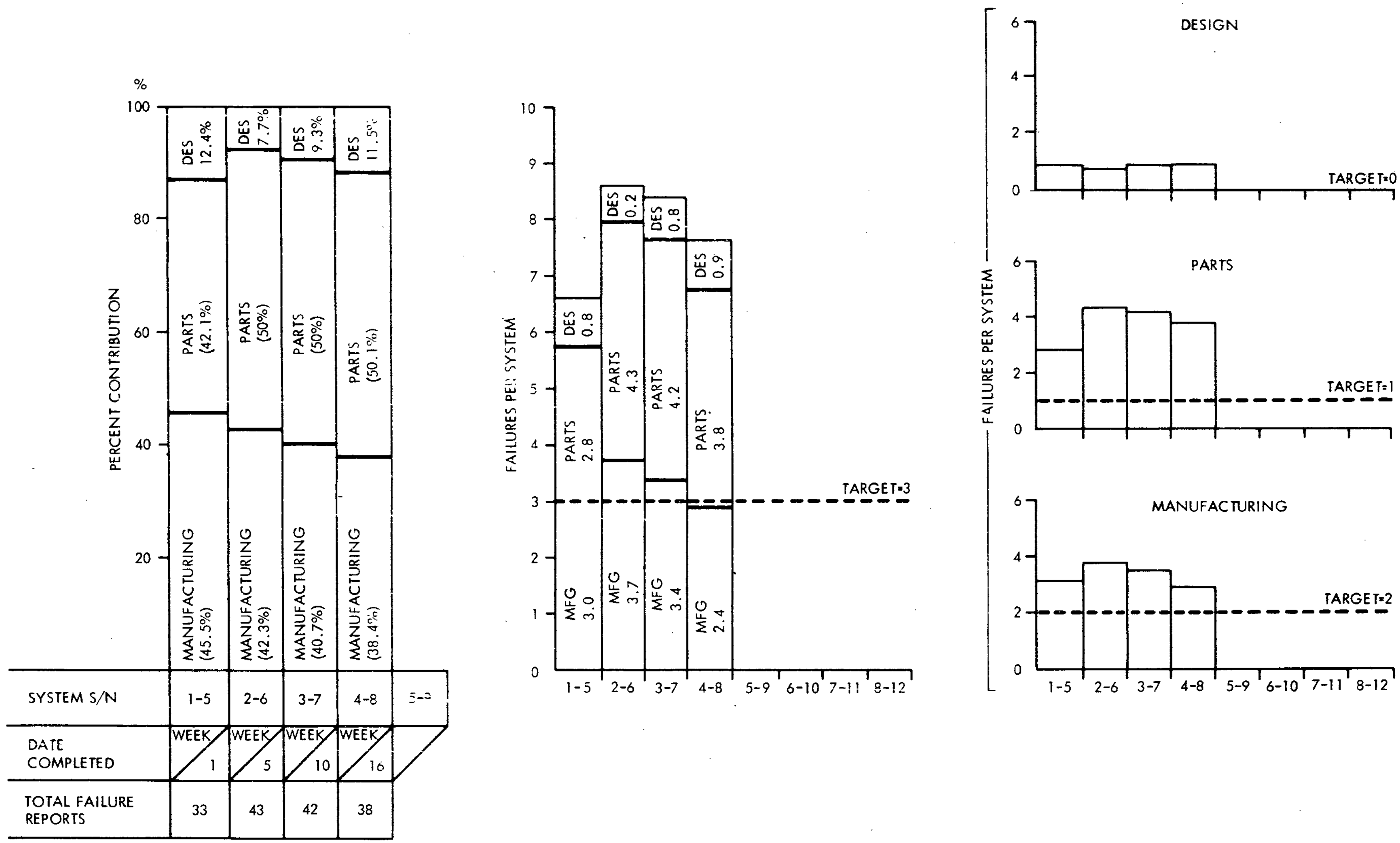

Figure 8. Performance Indicators-System Burn-in

In this manner, specific indicators were provided which were used to direct program effort in the implementation of corrective actions and priorities. These indicators provided a direct analogy of the 600 hour MTBF to engineering and production management. These indicators were based on a moving average of five systems through the appropriate test cycle, Diagnostic, Burn-In, and AGREE, such that the learning curve or effect of improvement or degradation with time could be assessed.

Maturation of the production material control, troubleshooting, and training effectiveness was measured through indicators of manufacturing days per system (normalized) for each type of system test, as shown on Figure 9. In this manner, dynamic assessment of test span times established in the Production Plan, were evaluated.

Within this structure, an assessment was made of the effectiveness of the program flow and inspection process, as compared with the elements directly associated with the physical process of troubleshooting and repair accomplished in order to provide factual data which was essential for the corrective action decisioning process.

RELIABILITY CONTROL GROUP

The project organization evolved for this program is shown in Figure 10. The Reliability Control Group (RCG), was organized to basically assess the relationship of the design to the manufacturing operation in terms of relative contribution to the 600 hour MTBF. The composition of the Reliability Control Group consisted of representatives of the following functions:

1. Design Engineering
2. Quality Assurance
3. Manufacturing Engineering
4. Production Test
5. Material Control
6. Components Engineering
7. Program Office
8. Environmental Test Laboratory

The chairmanship of the Reliability Control Group was provided by the Reliability Engineering organization. Resident customer representatives also attended Reliability Control Group meetings.

The members of the RCG were vested with the authority to act for their respective department supervisor. The RCG representatives were either committed on a full-time basis to the duties associated with this function or gave first priority to support as requested by the Chairman of the RCG.

The Reliability Control Group was charged with the responsibility of categorizing, and classifying all failures experienced during the System test programs. Classification of system failures, relevant or nonrelevant, was based on the cause of each failure. The categories of failure causes are shown in Figure 11. Since this was a group composited from each program function, authority had to be vested in each member

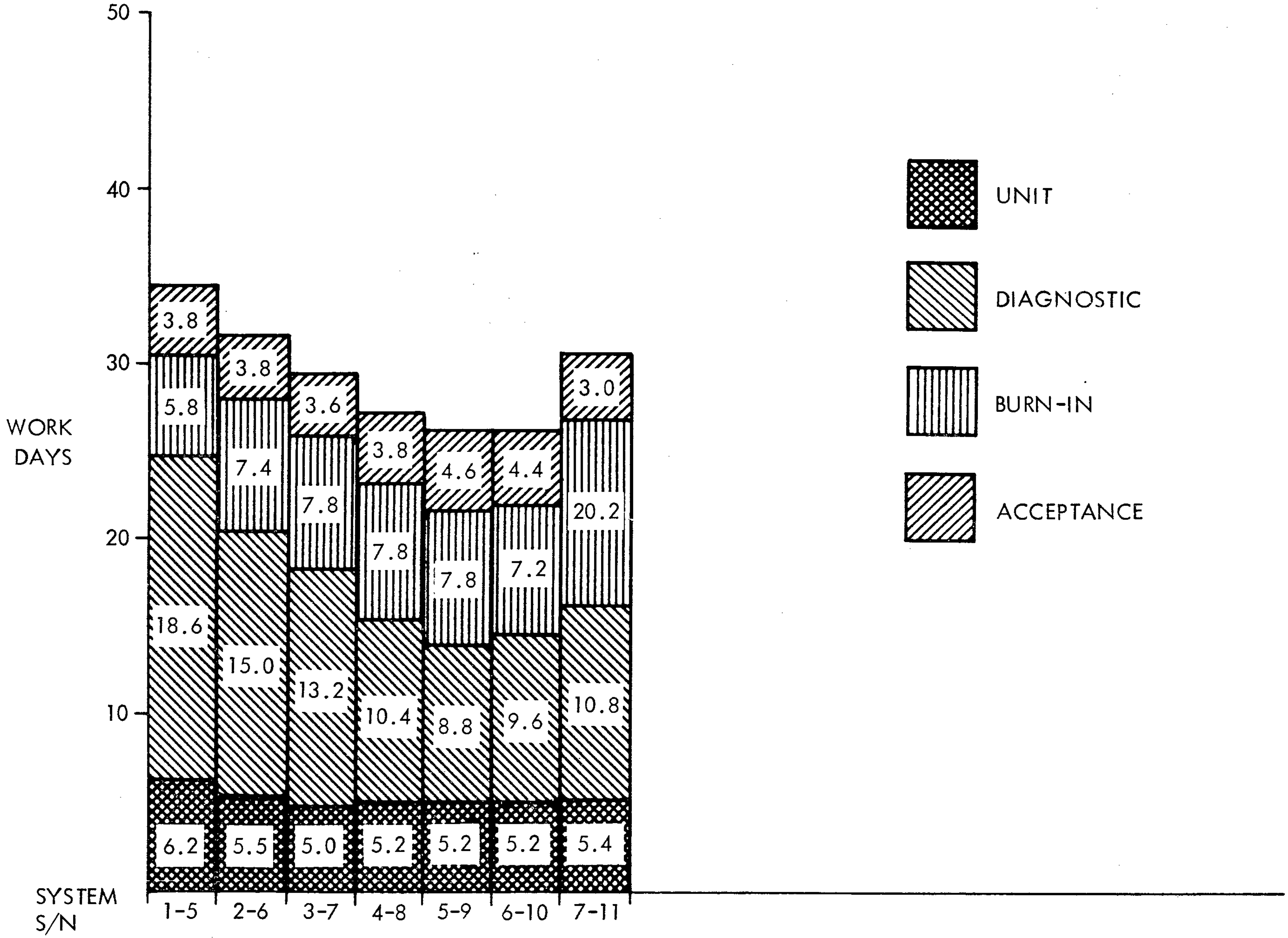

Figure 9. Test Span Times

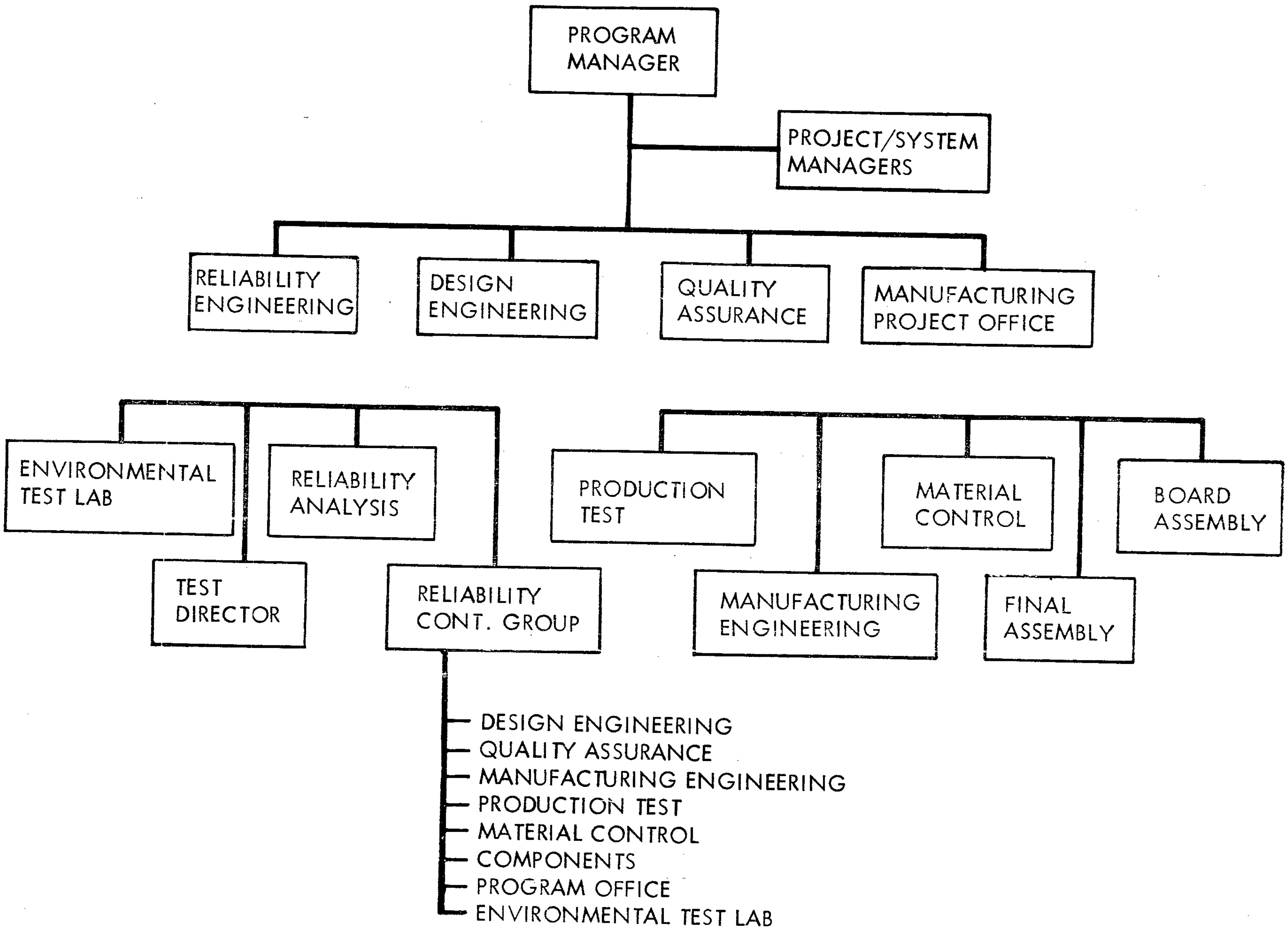

Figure 10. Program Organization

FIGURE 11

FAILURE CAUSE CATEGORIES

CATEGORY	FUNCTION	RESP INDIVIDUAL
1. D - DESIGN		
DA - Failure in this area would place the cause of failure directly upon the design of the equipment, i.e., the design of the equipment caused the part in question to degrade or fail, resulting in an equipment failure.	Design	O. Stress
DB - Failures caused by inadequate process details, test processes and procedures.	Manufacturing Engineering	W. Fab
2. W - WORKMANSHIP		
Failures caused by poor workmanship during the equipment construction, testing, or repair prior to start of test.	Manufacturing Engineering	W. Fab
3. PD - PART DESIGN		
Parts whose failures directly resulted from the inadequate design of the part.	Components Engineering (Vendor)	P. Part
4. PW - PART WORKMANSHIP		
Result of inadequate workmanship during assembly of the part, or inadequate inspection or testing.	Components Engineering (Vendor)	P. Part
5. OTHER		
The category OTHER includes any relevant failure not falling into the above defined categories.	- - -	- - -
6. TE - TEST EQUIPMENT INDUCED FAILURES		
Failures induced by test equipment, or resulting from inadequate test equipment design.	Environmental Test Laboratory	A. Shake

at a working level such that he could represent and commit resources of his respective department. To facilitate this, failure categories were personalized by assigning for each failure category as shown on Figure 11, a specific individual which represented the function, which after thorough investigation, was found to have caused the failure incident.

The troubleshooting, repair and retest sequence of the program was identified through a flow diagram issued as a Program Directive, shown as Figure 7. In this manner, assessment of daily responsibility was achieved through the RCG, which provided a direct measure of the cohesiveness of the production and inspection flow process through which all failed assemblies were processed in order to realize the specific elements necessary to fully categorize each failure occurrence. In this manner, the quality and responsiveness of each individual assigned to the RCG function, which met a minimum of four times a week, was continually under evaluation.

Concurrent with the backward flow of the QRC Failure Analysis Loop, there was a high volume of production material being processed in an upward direction, in order to prepare systems for delivery. As a result of these two flows, special controls were required to assure full data was realized from each failure, such that each failure report could be categorized and classified. From this process, failure patterns and trends were identified so that design, manufacturing, and parts corrective action could be defined and implemented.

A Control Point under the direction of Reliability Engineering in association with Material Control, Design, and Quality Control was established to inventory and process all system failures through the QRC loop.

Failures from each of the Black Box, Diagnostic, Burn-In, Acceptance and AGREE tests were placed in color-coded tote boxes so they could be identified within the troubleshooting, repair, and retest operations, so that pre-established priorities over the upward flow of production could be applied and maintained. The color coding also provided each operator, tester, and inspector the indicator for determining his daily work schedule as a function of the standing priorities.

In order to fully direct the impact of the quality of data entered by the testers and repair operators on each Failure Report, several significant reports were distributed in order to provide these personnel with an overview of the total program, and specifically the status of the device they were qualified to test or repair as it progressed through the AGREE test. Typical of these reports were:

1. A weekly tally of open failure reports from each test level, starting with major module tests, Black Box test, Acceptance test, Diagnostic, Burn-In and AGREE. Through this report, it was possible to identify, using histograms, those functions which were impacted by the highest quantity of failures on a daily basis. The report showed the results achieved during the week, by the QRC process and RCG actions,

as evaluated by the net rate of closure, as a function of test activity over each week. Typical chartings are shown as Figure 12.

2. A daily report was issued to line supervision and company management to provide status, of the total number of relevant AGREE failures compared with total operating time, with respect to the accept and reject decision criteria of the sequential test plan.

3. Plots of time vs failures (sequential) were maintained in the Environmental Test Laboratory and Manufacturing areas so that test, repair, inspection personnel on the line could realize and identify with progress through the AGREE test as a direct function of their efforts. This identity has been initiated by developing with these personnel, the example of the potential of 129,600 modes of failure within AGREE, during training sessions associated with completing failure reports. Since the sequential plot associated with AGREE allowed no more than 20 failures to realize an accept decision, (Figure 4), the awareness was demonstrated quite frequently by specific questions from line inspection test and repair personnel, showing great concern as the plot of real data stepped toward and away from the reject criteria.

4. A weekly cumulative summary of all experience in Diagnostic, Burn-In, and AGREE tests was provided to middle and top management to show status with respect to a major milestone of the program - successful completion of AGREE.

AGREE IMPACT ON PRODUCTION

In order to relate the impact of the AGREE Qualification Test on the production plan, indicators were developed within the AGREE span time such as:

a. Start, and finish time for the AGREE Qualification Test, since delivery was restricted until the test was completed.

b. Need to achieve 5,000 hours in AGREE of a total 6,240 hours in order to fully commit a production schedule for delivery of all contract quantities. This block of data was felt to provide a high level of intuitive confidence in the design.

c. Identity of failure patterns and problems associated with the production yield and performance of critical modules associated with the end product was essential. This task was accomplished through Producibility Audit teams comprised of quality, manufacturing engineering, design, and reliability personnel, in order to smooth the flow of production material up such that program resources were not impacted or committed when the need for failure analysis, troubleshooting and repair action was occasioned as a result of system failures.

Weekly reports were also prepared to assess corrective action realized and results obtained as a result of the Reliability Control Group operation. From the chart shown in Figure 13, a one-to-one correlation was accomplished in many cases of specific failure reports to define problem areas or potential problems under investigation through a formal process resulting in the preparation of a Design Assurance Corrective Action Request (DACAR). The resultant corrective action, once consummated in a design change,

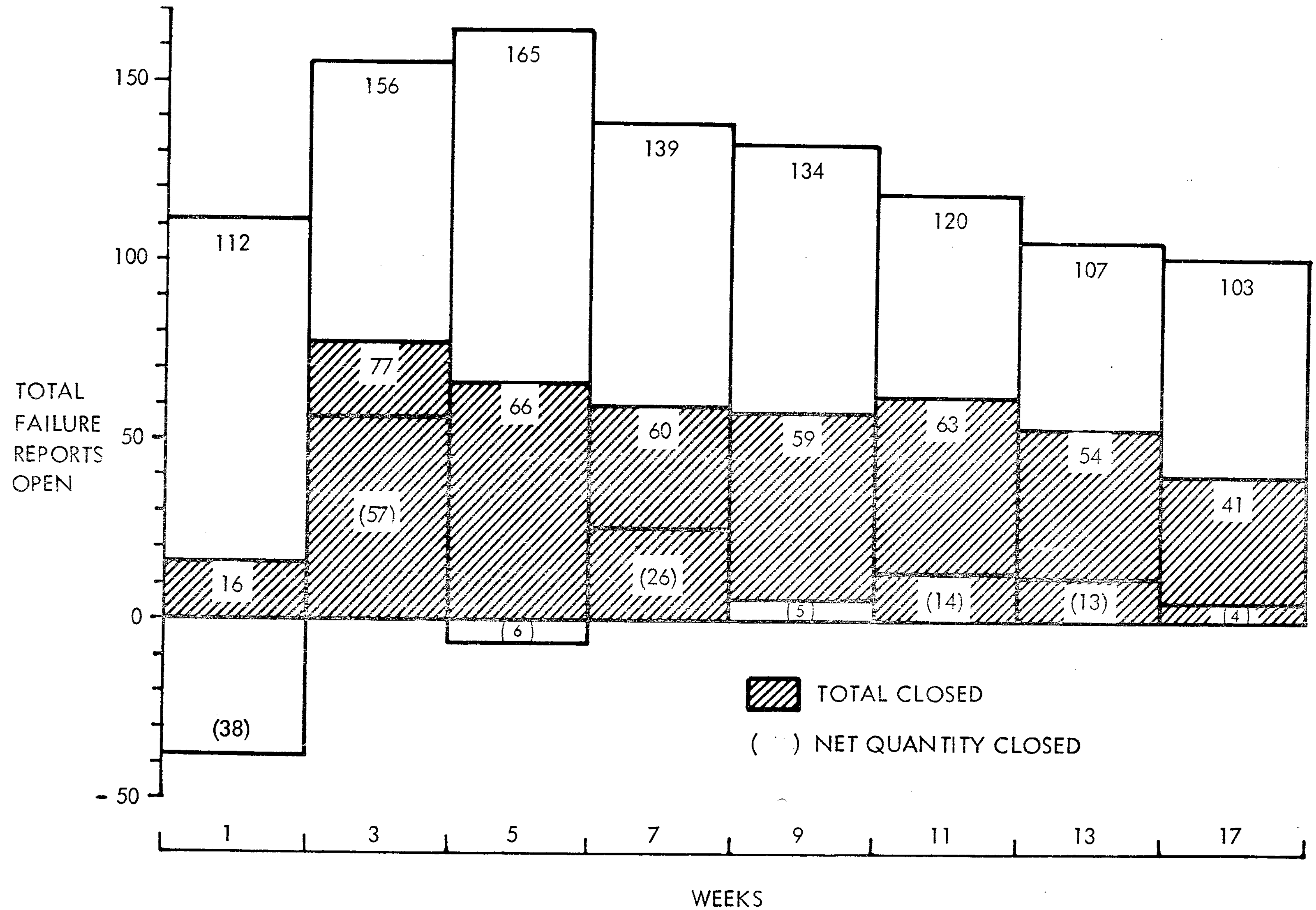

Figure 12. Closure Rate of Failure Reports

	TOTAL FAILURES (S/N 4-8)	FAILURES/ SYSTEM	REDUCTION BASED ON CORRECTIVE ACTION	REDUCTION OF FAILURES PER SYSTEM	RESULTANT FAILURES PER SYSTEM	TARGET
	38	7.61	16	3.2	4.4	3
MFG	15	2.92 (38.4%)	9	1.8	1.12	2
DESIGN	4	0.88 (11.5%)	3	0.6	0.28	0
PARTS	19	3.81 (50.1%)	4	0.8	3.00	1

DACAR 002/009	CONNECTOR PROBLEM	1
DACAR 004	TEST EQUIPMENT INDUCED FAILURES	2
DACAR 008	RESISTOR FAILURES	2
DACAR 014	MECHANICAL PROBLEM	2
DACAR 015	BOARD/CAN-PROBLEM	4
DACAR 017	CABLE HARNESS PROBLEM	1
DACAR 022	TUBE FAILURES	1
DACAR 027	RECEIVER PROBLEM	1
DACAR 029	CAPACITOR PROBLEM	1
DACAR 033	TRANSFORMER PROBLEM	1
	TOTAL	16

Figure 13. Corrective Action-System Burn-in

change to a process detail, or Inspection Instruction, represented the closed loop to account for each of the significant failure reports processed through the daily Reliability Control Group meetings. As such, this system provided the incremental steps in reducing the quantity and rates of failures throughout the build and extensive test cycles associated with this program.

Periodic reliability assessments were developed, based on point estimates of MTBF realized through the AGREE test. A marginal MTBF would allow an accept decision to be made during the Qualification test, therefore, it was necessary to identify additional product improvement actions required to achieve and maintain a high probability of success through the subsequent eight production sampling tests. This product improvement if lacking, could further increase the total liability of this program by delaying the production build effort which, in turn, would result in additional production sampling tests.

Assuming upon completion of the AGREE Qualification Test, a 345 hour MTBF were realized, it would be possible to make an accept decision, as a result of the manner in which the test was defined.

The calculations of a "best estimate" MTBF of 312 hours, shown earlier, illustrates how an accept decision could be realized. Computations show that a producer's risk of 44 percent would exist for each subsequent test if no product improvement were made and the true MTBF was 312 hours.

If a product has a measured MTBF of 345 hours and it is subjected to a sequential test based on a contract specified MTBF of 600 hours, calculations show that a 72 percent probability of success can be expected. Equating this mathematically in the following form:

$$P\,(\text{success}) = (0.72)^8 = 0.07 = 7\%$$

where success equals an accept decision on all of the eight production sampling tests. This low probability of success provided management with the incentive to continue effort in the direction of improvement in key areas identified by problem and pattern failures as a result of the Reliability Control Group activity.

A natural tendency of personnel and functions to shift responsibility was initially experienced when the RCG mode of operation was implemented. The desires to let the RCG provide all direction and assume all responsibility for achieving the 600 hour MTBF was quickly corrected. A program must function through each of its constituent parts. A program manager cannot abdicate his responsibilities to a Reliability Control Group. The Reliability Control Group and Reliability Management, must provide indicators to the program of levels of achievement and of success toward achieving a contract specified mean-time-between-failure. The RCG must also provide directions and controls, but it cannot do the work of the designer, the manufacturer, or the tester.

In summary, reliability must effect a smooth integration of quality efforts into the engineering, the production, and the test programs. When, as has been shown, by the example in this paper, this integration of effort has been achieved, then quality has become Reliability.

To some Quality has always had the broad responsibilities exercised on this program. If so, reliability has added nothing.

To most of us, however, the success of the system described above represents an expansion of the usual quality efforts- a transformation of quality to a broader scope which can be called Reliability.

This broader scope, whatever it is called, means progress toward better products and services. In this program the end result provided the validation of this concept.

AN INTEGRATED COMPUTERIZED RELIABILITY MONITORING PROGRAM FOR AIRCRAFT SYSTEMS AND COMPONENTS

by

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INTRODUCTION

Since the introduction of the Jet Transport, the Air Transport industry, specifically the major commercial carriers, has been faced with increased costs that are incurred in maintaining these highly sophisticated aircraft at an acceptable reliability level.

Pan American spends currently about $150 million a year on aircraft maintenance, and this figure is expected to increase to about $440 million by 1980.

During the early 1960's it became apparent to the FAA that due to the tremendous growth of the air transport industry and increasing complexity of the aircraft they could no longer maintain as close a control as was needed over the performance and more specifically, the overhaul time limits on aircraft, air-frames, and components parts.

It was also felt that the development of the maintenance philosophies and policies was lagging behind the technological progress, and it was necessary to find new approaches in this increasingly complex field. During the same period, the aerospace industry and defense bodies developed new theories of Maintainability and Reliability, and the attitude of A/C maintenance people underwent significant changes.

Concurrently, Reliability programs were initiated by the airlines. Basically, these programs operate on the principle that each individual airline will develop its own Reliability Procedures and will be responsible for the performance and overhaul time limits for its equipment, being required to report on this performance to the FAA monthly.

The programs developed by Pan American World Airways strived to pinpoint problems before they became chronic and to trigger corrective action.

The first difficulty encountered was the sheer volume of data to be processed, (Pan American is monitoring more than 1000 types of components). Second, the cost factor could not be taken into consideration due to lack of proper data. Last but not least, the early systems did not generate quantitative criteria for performance monitoring, and the decision where to act first, was taken intuitively.

The proposed program, parts of which are already implemented, will attempt to correct those dificiencies and will automatically supply the processed data, necessary at various levels of decision making.

The technique employed helps in detecting unfavorable trends in the system and/or unit performance and provides maintenance

costs and other pertinent information necessary to undertake any improvement or corrective action. The alerting mechanism takes into account possible random variation of the monitored parameters and generates the alerts only when the parameters deviations are statistically proven significant.

The program attemps to optimize such parameters as cost, utility, and response within the reliability function of aircraft maintenance system.

DESCRIPTION OF THE PROGRAM

The program is based on the general concept of Statistical Control. It computes, in its initial stage, control limits from data collected during 12 months operation of aircraft systems and components, then as a monthly routine, compares current performance parameters against these limits. When the limits are exceeded or undesirable trends are detected, alerts at various levels are generated.

There are three types of alerts:

Type 1 - When a significant undesirable trend is detected.

Type 2 - When a sudden deterioration in the performance of a component occurs.

Type 3 - When the performance of a component is significantly deteriorated over a longer period.

For each alert type, well defined corrective actions and/or follow-ups are triggered.

The Program monitors two types of parameters:

a. The year-to-date average system discrepancy rate and unscheduled removal rate for components. In this way seasonal fluctuation and random monthly variations can be disregarded, and general trends are detected.

b. The absolute number of monthly system discrepancies and component removals, which will show any sudden changes not reflected in the yearly average.

INPUT

In order to perform the analysis and to generate the necessary alerts, the following data is collected, processed and/or stored:

1. Number of system discrepancies (both component and non component related.)
2. Number of unscheduled removals of components, by month, for 13 months.
3. Number of flight and unit hours, by month, for 13 months.
4. Number of scheduled removals, by month.
5. Average Labor M/H and Material Dollars for maintenance work, by component code number, by month, for 13 months.
6. Numbers of confirmed failures by code number, by month, for the previous 12 months.
7. Detail data for the current month, system discrepancies and component removals by A/C tail number, station, etc.

MONITORING PROCEDURES

The following describes the details of the procedure for determining control limits for components. The procedure for systems is similar except that the total system discrepancies, both component and non-component related, will be substituted for the number of unscheduled removals (failures) for the components.

INITIATION PROCEDURES

Since the number of actual failures in a given month is not known immediately, the number of unscheduled removals is used for the purpose of evaluating component performance.

One parameter to be monitored is the year-to-date removal rate.

If we assume that the number of units removed from a population operating a given time is Poisson distributed, control limits can be computed by means of the following equations:

$$UCL^{(1)} = \frac{YRR}{2n_o}\chi^2_{f=2(n_o+1);\,1-P_1}$$

$$LCL^{(1)} = \frac{YRR}{2n_o}\chi^2_{f=2n_o;\,1-P_2}$$

Where:

UCL - Upper Confidence Limit
LCL - Lower Confidence Limit
YRR - Removal Rate over initial 12 months.
f - Number of degrees of freedom
n_o - Number of removals from which the YRR is computed.

P_1 - Upper Confidence Level
P_2 - Lower Condidence Level

P_1 and P_2 are arbitrarily chosen .05 and .95 respectively to obtain a 90% confidence level.

MONTHLY ROUTINE

The following steps will be performed each month:

1. Determine the average Removal Rate for the last 12 months including the current month (YRR2).

2. Compare with UCL. If UCL is exceeded, generate Type-3 alert.

3. Compute maximum acceptable number of unscheduled removals (Max. UR) as follows:

   a. Multiply YRR2 by the number of operating hours of the component in the current month. By using this value as a Poisson distribution parameter, (C), solve for Max. UR the equation:

$$P(x \leq \text{Max.UR}) = \sum_{X=0}^{\text{Max.UR}} \frac{c^x \exp(-c)}{x!} = P3$$

   P_3 was initially assigned the value of 0.95.

4. Compare the number of unscheduled removals for the current month against Max. UR. If it exceeds the Max.UR, generate Type-2 alert.

5. Compute the Regression coefficient (k) over the last 12 months component Removal Rates.

6. Determine the average Removal Rate over the last 12 months not including the current month. (YRR1).

7. If $k>0.1$ and YRR2>YRR1, generate Type-3 alert.

8. Check whether YRR2 was under LCL for the last three months. If yes, recompute Control Limits.

9. Check whether YRR2 was over UCL for the last three months. If yes, investigate, and if necessary, recompute control limits.

10. Produce exceptions and detailed reports (see Output)

OUTPUT

Depending upon the type of alert generated, the following reports will be produced. Refer to Exhibit 1 for sample output reports.

SYSTEM ALERTS

Reports produced for Type 3 and type 2 Alerts

1. Report 1 giving performance information for the current month and previous 12 months for the alerted systems.

2. Report 2 giving performance information for the current month and previous 12 months for all components associated with the alerted system(s), even if the components themselves are not alerted.

3. Report 3 giving detailed historical information by Serial No., A/C, station, etc. for all components covered under Report 2.

Reports produced for Type 1 Alert

1. Report 1 giving performance information for the current month and previous 12 months for the alerted systems.

COMPONENT ALERTS

Reports produced for Type 3 and type 2 Alerts

1. Report 2 giving performance information for the current month and previous 12 months for the alerted components.

2. Report 3 giving detail history information by Serial No., A/C, station, etc. for all components covered under Report 2.

Reports produced for Type 1 Alert

1. Report 1 giving performance information in the current month and previous 12 months for the alerted components.

In addition, for system and component alerts of type 3 and 2, existing EDP reports, Reliability Analysis Report, Detailed Removal list and Shop Finding Reports for the alerted components and Serial Numbers will also be produced.

The program will also generate a complete Reliability Component Monitoring Report giving performance information for all components, alerted and non-alerted.

FOLLOW-UP AND IMPROVEMENT

The program attempts to optimize the parameters of cost, utility and response, but its

operation may require trade-offs between conflicting constraints.

In order that the program will be a dynamic one, it must be provided with means of adjustment while in operation.

There are three variables which were initially given arbitrary values, but they can be readjusted as necessary:

1. The sensitivity to long term changes. It is determined by the confidence level used in computation of UCL and LCL. Larger values for P_1 and P_2 will increase sensitivity and vice versa.

2. The sensitivity to sudden changes. It is determined by the confidence level used in computation of Max.UR. A smaller value for P3 will increase the sensitivity and vice versa.

3. The amount of components monitored. At implementation, a certain group of components were selected for monitoring. Later on, components may be added or dropped from the group according to the degree of practical return gained from the monitoring.

In order to improve the accuracy of the program, a periodic review will be made of those Control Limits which are continually exceeded, in order to determine whether they are realistic.

This activity is necessary due to the fact that some limits were initially computed from insufficient data, or before the component performance reached a state of equilibrium.

PRESENT STATUS

At the present time, the following parts of the integrated program are implemented and operating independently:

1. Reliability Component Monitoring Program. This program generates a monthly report covering more than 1000 components. See Exhibit 2.

2. Actuarial Analysis Reports. These reports are produced monthly on a request basis and twice a year for all components. See Exhibit 3.

3. Detailed list of components removed in the last year containing information on each removal. See Exhibit 4.

4. Delay Reports. These reports are published monthly and contain a description of all maintenance delays that occurred during the month.

5. Shop Findings. For a group of 350 selected components, shop findings information is collected. The accumulated data is presented monthly after being sorted by component code number. See Exhibit 5.

CONCLUSIONS

Aircraft maintenance of today, require that management and Reliability functions will be provided with fast and detailed indication of possible problem areas, so that corrective action can be initiated in time.

The integrated system presented will collect and process vast amounts of data, and by means of

statistical tools, flag out systems and components that show any undesirable trend in their performance.

The use of Electronic Data Processing will give a reasonable fast response. While the system is rather complex, it output presents in a simple form the most important facts on performance of systems and components.

REFERENCES

1. Hald, A. Statistical Theory with Engineering Applications, Wiley, N.Y., 1957 P. 722.

EXHIBIT I

MONITORING SYSTEM REPORTS

REPORT #1

ATA SYSTEM/SUBSYSTEM ___ T/E ___

YRR2	UCL	LCL	YRR1	MDR	MD	MAX	MD	CURRENT MO. MAINT. COST		PREV. 12 MO. AVG. MAINT. COST		MONTH U/R	MONTH S/R
								LABOR M.HRS.	MAT. DOLLARS	LABOR M.HRS.	MAT. DOLLARS		

REPORT #2

CODE NO.	KEYWORD	YRR2	UCL	LCL	YRR1	MRR	MONTH U/R	MAX. U/R	MONTH S/R	CURRENT MONTH MAINT. COST		PREV. 12 MONTH AVG. MAINT. COST		CONF.FAIL.RATE
										LABOR M.HRS.	MAT. DOLLARS	LABOR M.HRS.	MAT. DOLS.	

REPORT #3

DETAIL FOR SYSTEMS &/OR COMPONENTS
HEADING (FOR COMPONENT OR NON-COMPONENT RELATED ITEMS)
XXXXXXXXXXXXXXXXXXXX

A/C	STA	DATE	POS.	SCHED.REM. S/N	UNSCHED.REM. S/N	LOG PAGE NO.	INSP. CARD. REF.	DELAY REF.	DELAY TIME MAINT.	DELAY TIME TOTAL	SOURCE CODE

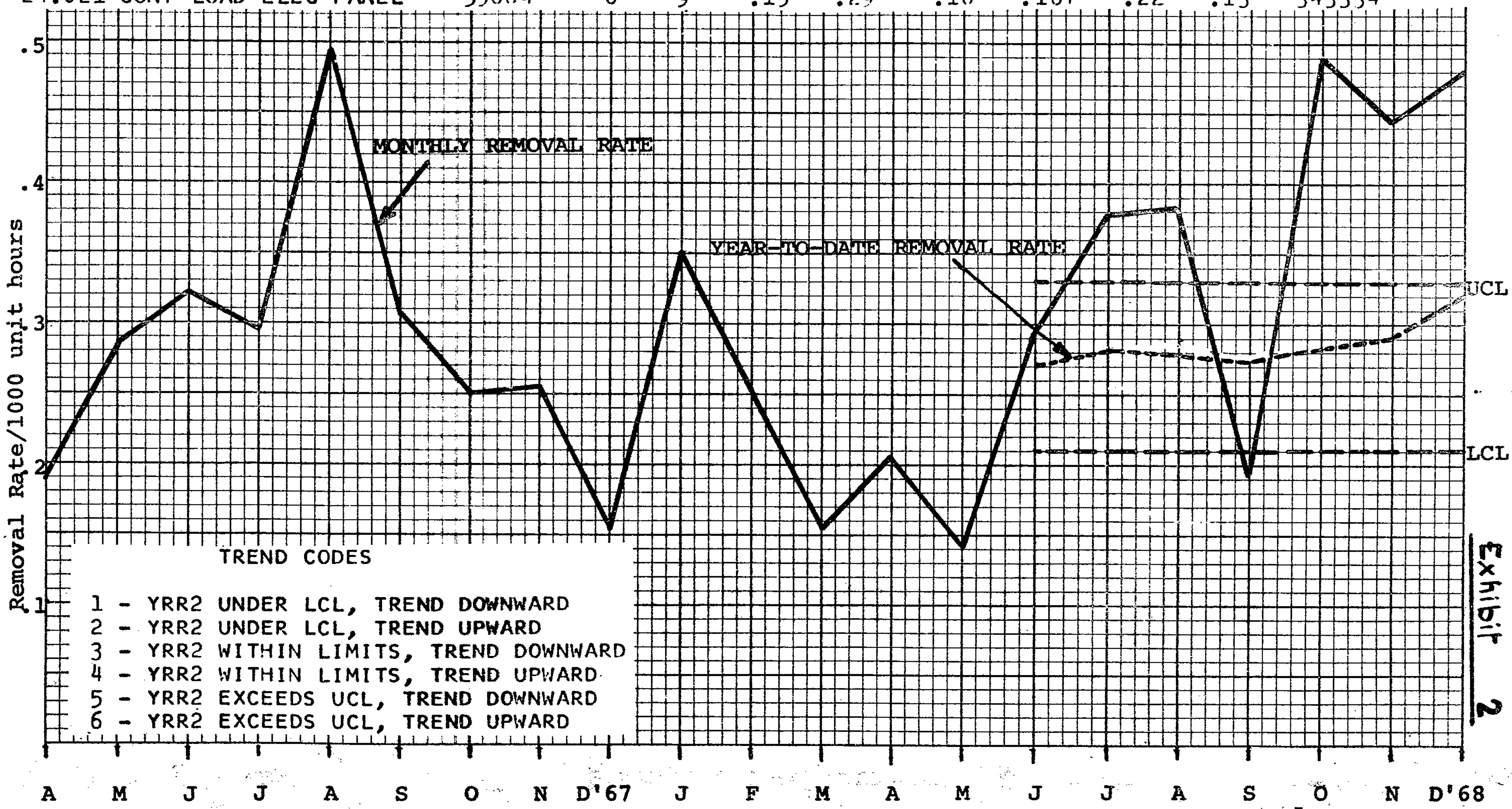
NOTES:

1. ALL MAINT. COSTS AND REMOVALS/DISCREPANCIES RATES ARE PER 1000 FLIGHT OR UNIT HOURS.
2. YRR1 - 12 MONTH CUM.AVG.RATE NOT INCLUDING THE CURRENT MONTH.
3. YRR2 - 12 MONTH CUM.AVG.RATE INCLUDING THE CURRENT MONTH.
4. UCL - UPPER CONTROL LIMIT (RATE).
5. LCL - LOWER CONTROL LIMIT (RATE).
6. MDR - CURRENT MONTH's DISCREPANCY RATE/1000 HOURS.
7. MD - CURRENT MONTH'S DISCREPANCIES.
8. MAX. MD - MAXIMUM ACCEPTABLE DISCREPANCIES FOR THE CURRENT MONTH.
9. MONTH U/R - MONTHLY UNSCHEDULED REMOVALS
10. MONTH S/R - MONTHLY SCHEDULED REMOVALS.
11. MRR - CURRENT MONTH'S REMOVAL RATE.
12. MAX. U/R - MAX. ACCEPTABLE UNSCHEDULED REMOVALS FOR THE MONTH.
13. SOURCE CODE - FLIGHT OR GROUND ITEM.
14. SYSTEM DISCREPANCIES INCLUDE BOTH COMPONENT AND NON-COMPONENT RELATED ITEMS.

Exhibit 2

COMPONENT RELIABILITY MONITORING PROGRAM
BOEING 727 - REPORT FOR DECEMBER 1968

5-2-1	KEYWORD	C/N	UR	MAXUR	MRR1	MRR2	YRR1	YRR2	UCL	LCL	TREND	
24.031	TRANS AY-CSD GENERATOR	55691	11	21	1.16	.70	.67	.63↑	.86	.65	433331	ULC
24.026	COOLER-OIL CSD	54458	[illegible]	12	.48	.13	.29	.26*	.45	.29	433311	ULC
24.041	IND-OIL TEMP CSD	57506	5	7	0.00	.32	.18	.21↑	.22	.12	444334	
24.201	GENERATOR-40 KVA	52359	10	12	.15	.48	.29	.32↑	.33	.21	433444	
24.056	REGULATOR-VOLTAGE	52363	4	10	.20	.19	.26	.26	.27	.17	444633	
24.053	PANEL-GEN CONTROL	52362	8	16	.20	.38	.33	.34	.48	.34	331414	
24.005	BREAKER-GEN&BUS TIE	59270	0	3	0.00	0.00	.01	.01	.03	.00	333333	INLM
24.021	CONT-LOAD ELEC PANEL	59064	6	9	.15	.29	.16	.18↑	.22	.13	343334	



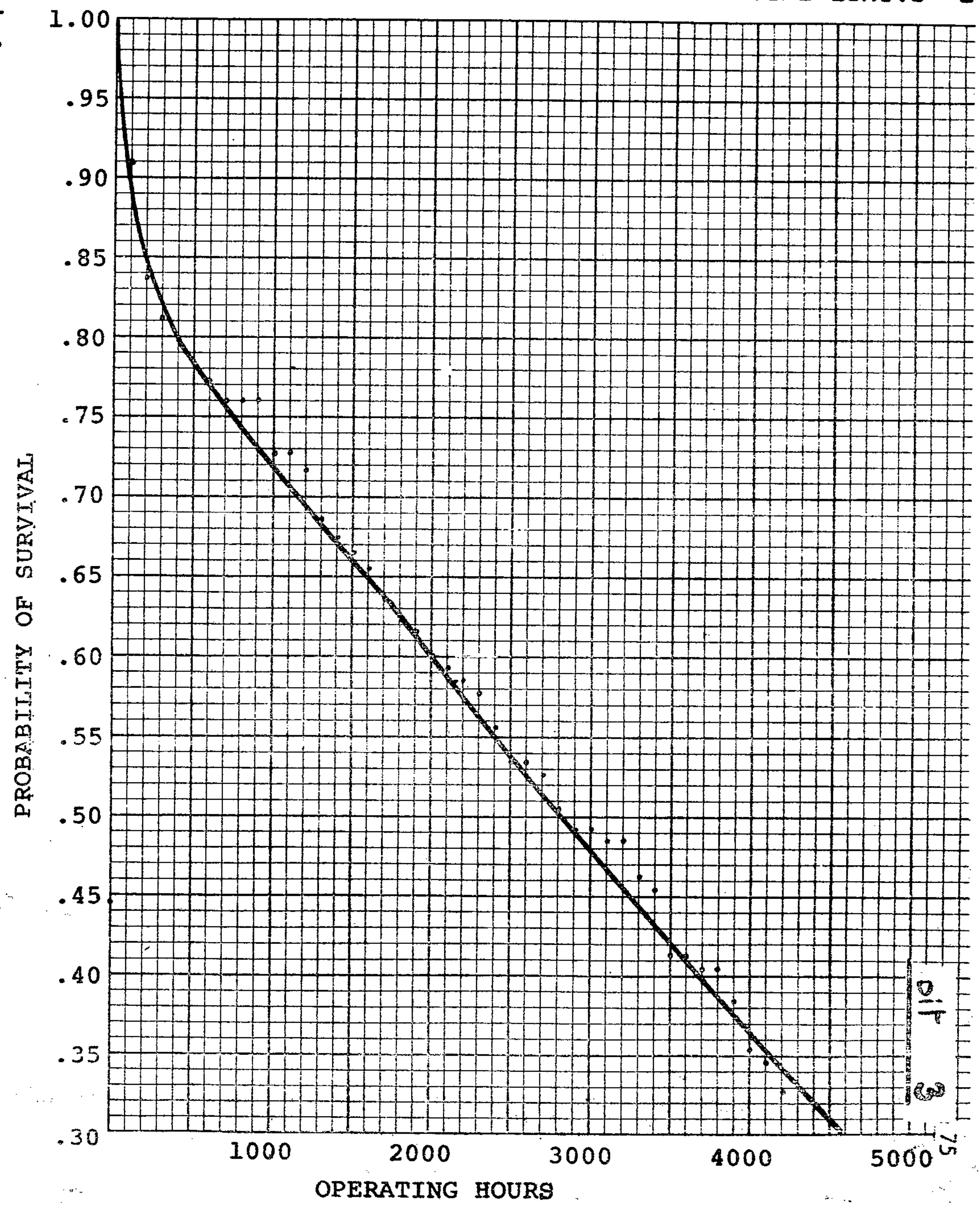
TREND CODES

1 - YRR2 UNDER LCL, TREND DOWNWARD
2 - YRR2 UNDER LCL, TREND UPWARD
3 - YRR2 WITHIN LIMITS, TREND DOWNWARD
4 - YRR2 WITHIN LIMITS, TREND UPWARD
5 - YRR2 EXCEEDS UCL, TREND DOWNWARD
6 - YRR2 EXCEEDS UCL, TREND UPWARD

P - 545 / TAPE 2101 * RELIABILITY ANALYSIS REPORT FROM 06/01/68 TO 11/30/68 *

ENTITY-E T/E-10 SYSTEM-K4 CODE NO.-52359 KEYWORD-GEN40KVA 5-2-1-REF. 19-36-47 TIME LIMITS--L

INTERVAL	TRAVERS U/R	--TSO UNSCHEDULED REMOVALS- COUNT	P/C	P/S	P/ACC.
00000-00099	66.82	6.	.090	.910	.090
00100-00199	63.51	5.	.079	.838	.169
00200-00299	62.50	2.	.032	.811	.201
00300-00399	61.10	1.	.016	.798	.217
00400-00499	59.67	1.	.017	.784	.234
00500-00599	66.01	1.	.015	.772	.249
00600-00699	63.65	1.	.016	.760	.265
00700-00799	65.16	.		.760	.265
00800-00899	66.67	.		.760	.265
00900-00999	70.54	3.	.043	.727	.308
01000-01099	67.58	.		.727	.308
01100-01199	67.35	1.	.015	.716	.323
01200-01299	69.38	3.	.043	.685	.366
01300-01399	68.02	1.	.015	.675	.381
01400-01499	67.57	1.	.015	.665	.396
01500-01599	66.95	1.	.015	.655	.411
01600-01699	65.23	2.	.031	.635	.442
01700-01799	64.04	1.	.016	.625	.458
01800-01899	68.27	1.	.015	.616	.473
01900-01999	76.96	2.	.026	.600	.499
02000-02099	82.25	1.	.012	.593	.511
02100-02199	79.23	1.	.013	.585	.524
02200-02299	77.13	1.	.013	.577	.537
02300-02399	78.12	3.	.038	.555	.575
02400-02499	75.79	3.	.040	.533	.615
02500-02599	74.19	.		.533	.615
02600-02699	73.66	1.	.014	.526	.629
02700-02799	77.06	3.	.039	.505	.668
02800-02899	73.41	2.	.027	.491	.695
02900-02999	69.09	.		.491	.695
03000-03099	65.18	1.	.015	.484	.710
03100-03199	64.31	.		.484	.710
03200-03299	63.42	3.	.047	.461	.757
03300-03399	58.47	1.	.017	.453	.774
03400-03499	55.10	5.	.091	.412	.865
03500-03599	49.37	.		.412	.865
03600-03699	51.13	1.	.020	.404	.885
03700-03799	55.22	.		.404	.885
03800-03899	59.27	3.	.051	.383	.936
03900-03999	61.34	5.	.082	.352	1.018
04000-04099	59.03	1.	.017	.346	1.035
04100-04199	57.39	3.	.052	.328	1.087



1545 L

* SERVICE ANALYSIS CHECK LIST AS AT DECEMBER 31, 1968

E	A/C	POS.	SERIAL NO.	CODE NO.	T.L.	RF	KEYWORD	TSO/IN	I/N-HR	STA	R/REA	DATE/REM	TSO/REM	ATA
-	58	003	OM5253	-52359	6000	36	GEN40KVA	12	12	FRA	5441	05-16-8	2364	K4(
-	59	001	NJ2793	-52359	6000	36	GEN40KVA	3220	2895	MIA	5441	11-22-8	3731	K4(
-	59	001	SL4548	-52359	6000	36		4066	3563	000	1111	11-30-8	4129	K4(
-	59	001	TK3735	-52359	6000	36	GEN40KVA	1221	1840	JFK	5441	08-13-8	2179	K4(
-	59	001	UK3803	-52359	6000	36	GEN40KVA	1852	358	BER	5499	02-05-8	3029	K4(
-	59	001	ZK4165	-52359	6000	36	GEN40KVA	2685	1693	FRA	5440	03-20-8	2832	K4(
-	59	001	ZK4166	-52359	6000	36	GEN40KVA	2235	1535	FRA	5440	02-28-8	2393	K4(
-	59	002	RK3719	-52359	6000	36		1036	2500	000	1111	11-30-8	2162	K4(
-	59	002	XE512	-52359	6000	36	GEN40KVA	2486	1085	FRA	5440	02-01-8	2911	K4(
-	59	002	YK4057	-52359	6000	36	GEN40KVA	2540	624	BER	5491	12-04-7	2975	K4(
-	59	002	4063	-52359	6000	36	GEN40KVA	2327	1510	MIA	5441	06-07-8	3216	K4(
-	59	002	5833	-52359	6000	36	GEN40KVA	227	2455	SAL	5440	06-14-8	272	K4(
-	59	003	NL4273	-52359	6000	36	GEN40KVA	2722	1138	FRA	5440	05-30-8	3969	K4(
-	59	003	SZ721	-52359	6000	36		4420	3293	000	1111	11-30-8	4753	K4(
-	59	003	TL3750	-52359	6000	36	GEN40KVA	878	369	FRA	5441	12-11-7	1568	K4(
-	59	003	OF454	-52359	6000	36	GEN40KVA	1742	2385	JFK	5441	10-12-8	2571	K4(
-	60	001	XE513	-52359	6000	36	GEN40KVA	2928	1339	FRA	5441	09-18-8	4456	K4(
-	60	001	XK3978	-52359	6000	36	GEN40KVA	2276	327	JFK	5440	01-23-8	3288	K4(
-	60	001	YL4954	-52359	6000	36		2863	3021	000	1111	11-30-8	3446	K4(
-	60	001	OF690	-52359	6000	36	GEN40KVA	1258	3009	BER	5499	09-20-8	1270	K4(
-	60	002	XE439	-52359	6000	36			3259	000	1111	11-30-8	305	K4(
-	60	002	XK3981	-52359	6000	36	GEN40KVA	1769	672	JFK	5499	03-09-8	2740	K4(
-	60	002	5706	-52359	6000	36	GEN40KVA	734	1870	BER	5499	09-20-8	1885	K4(
-	60	002	5833	-52359	6000	36	GEN40KVA		1643	JFK	5440	04-14-8	227	K4(
-	60	002	6067	-52359	6000	36	GEN40KVA		3021	BER	5499	10-23-8	278	K4(
-	60	003	MM5095	-52359	6000	36		1896	2483	000	1111	11-30-8	3017	K4(
-	60	003	NJ2794	-52359	6000	36	GEN40KVA	4149	121	MIA	5491	11-12-7	4832	K4(
-	60	003	PM5316	-52359	6000	36	GEN40KVA	1184	1666	MIA	5440	04-24-8	1462	K4(
-	60	003	OF546	-52359	6000	36	GEN40KVA	1084	1944	BER	5499	07-14-8	1623	K4(
-	60	003	OL4316	-52359	6000	36	GEN40KVA	1580	878	JFK	5440	03-12-8	2368	K4(
-	88	001	UK3850	-52359	6000	36	GEN40KVA	2960	10	MIA	5440	12-29-7	3339	K4(

TIME LIMITS -------- LOW 6000 - HIGH 6000

COUNT - TIME REMVL. 8 UNSCH./REMVL. 132 IN FLIGHT 169 OTHER 424 TOTAL 733

/REMVL. - TIME REMVL. 25034 UNSCH./REMVL. 312075 IN FLIGHT 414425 OTHER1080853 TOTAL 1832387

Exhibit 4

DECEMBER 1968

SHOP FINDINGS ANALYSIS REPORT / COMPONENTS

REFERENCE ET-TE-A/C	ATA SYS.	COMPNT CODE	REMOVAL DATE MO-DA-YEAR	SERIAL NUMBER	SHOP COND	SHOP FINDINGS	T.S.O.	SHOP FINDINGS PART NO.	DEFECT	CAUSE	COUNT
SERIAL NUMBER											1
E 10 85	K4	52359	12 12 1967	NJ2794	8	05	00083		810		
REMOVAL DATE											1
E 00 00	K4	52359	11 04 1968	NJ2794	K	43	02339	RR-CONV TOTYPE16	715		
E 00 00	K4	52359	11 04 1968	NJ2794				SEALS		715	
REMOVAL DATE											2
SERIAL NUMBER											3
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	BEARINGS	678	522	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	SHAFT	678	522	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	END BELL	678	522	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	SEALS	678	522	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	03727	ROTOR	678	522	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	STATOR	678	678	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	AC BLOCK	678	522	
E 27 27	K4	52359	04 01 1968	NL4252	A	33	40000	SPINDLE	678	522	
REMOVAL DATE											8
E 00 00	K4	52359	08 13 1968	NL4252	N	21	123		809		
REMOVAL DATE											1
SERIAL NUMBER											9
E 10 86	K4	52359	11 15 1968	NL4269		91		SEALS&STUB SHAFT		715	
E 10 86	K4	52359	11 15 1968	NL4269	K	43	03153	RR-CONV	715		
REMOVAL DATE											2
SERIAL NUMBER											2
E 00 00	K4	52359	10 08 1968	NL4270	F	43	5048	BEARINGS 2EA		715	
E 00 00	K4	52359	10 08 1968	NL4270				DRIVE & SPINDLE		521	
REMOVAL DATE											2
SERIAL NUMBER											2
E 27 15	K4	52359	06 24 1968	NL4272	A	43	4544	DC BLOCK	244	715	
E 27 15	K4	52359	06 24 1968	NL4272				SEAL		715	
REMOVAL DATE											2
E 16 05	K4	52359	08 23 1968	NL4272				BEARINGS		715	

Exhibit 5

77

COMPUTER-AIDED RELIABILITY TECHNIQUES IN ELECTRONIC DESIGN

by

R.A. Nowacki
Textron's Bell Aerosystems Company
Buffalo, New York

INTRODUCTION

Modern electronic design process involves alternating creation and verification - an iterative process. As a design characteristic, reliability must also be verified, analytically or empirically, during the design and development phase. Some of the analytical techniques contrived in the mid-fifties are still being practiced with very few changes.

In the past three years there have been many evolutionary changes in some areas of reliability engineering and analysis. Some changes are due to the use of the digital computer as an instrument for implementing reliability theory. The use of modern electronic data processing (EDP) techniques has made the practice of the trial and error approach and various optimization techniques practicable and efficient.

This paper will discuss the more frequently used and most successful computer-aided techniques at the disposal of the reliability engineer in the design and analysis of electronic equipment for various applications and environments.

TECHNIQUES OF RELIABILITY ENGINEERING

The techniques to be discussed are not representative of a single product oriented reliability program, but are the outgrowth of reliability engineering programs carried out in a product and customer diversified company. They have stood the test of applicability to nearly all of the major reliability specifications as well as the particulars of individual equipment specification requirements. The severest challengers have been, of course, the electronics designers themselves. In developing a mutual understanding of each other's problems and fully cooperating to resolve them, a healthy, respectful relationship is attained.

The many reliability techniques practiced in the Electronics and Electro-mechanical Systems Engineering Departments at Bell Aerosystems factor in much of the constructive criticism provided by the design and development engineers. It may appear that "I am putting it on a bit thick" in describing the relationship of the reliability engineer and the designer. We do have our moments in the day-to-day stresses and strains of our jobs where over-zealousness tends to tear apart the best of relations and strain the association. Caution must be also exercised regularly

that we do not become overly sympathetic with the designer's problems and sympathize away product reliability and our position in the engineering department.

In formulating the management and technical responsibilities that define the means of complying with contractual requirements and provide engineering assistance in the design cycle, the reliability engineer applies a program of specialized techniques and methods. Many of these are more art than science. Some programs are selected from favorable experience while others are required by specification.

Reliability engineers have varied opinions on the effectiveness of most of the more common reliability design and analysis techniques. Some of these are extensions of engineering work performed by the designer, others constitute design review and process control practices, while still others are tasks unique to the reliability discipline. Figure 1 shows a general flow chart of a typical electronics design and development project with concurrent reliability support. It is during this phase, design and development, that the reliability engineer can best influence the design.

Figure 2 lists most of the better known general techniques employed by the reliability engineer in the design and development cycle. Many of these have been treated quite extensively in the literature. Therefore, I will discuss innovations of some of these techniques brought about in recent years through the use of large scale digital computers. The pace of today's programs dictates the need for an acceleration in implementing reliability techniques. In one respect reliability programs are a purchased service by customers who demand a dollar's value for every dollar spent. The total systems effectiveness philosophy often alarms program managers when the non-recurring costs of maintainability, reliability, human factors, safety, quality and others are compared to hardware costs on R&D or low-production, fixed price programs. In this respect, reliability is competing for a portion of available funds to do an effective job. The question very often arises: "Are these funds being allocated for tasks which generate effective results?" Some techniques exert more influence on design reliability than others. I believe the techniques discussed in this paper are noteworthy and aid in the attainment of product reliability while keeping engineering operating costs down. They are an answer to more rapid, more useful, and more efficient reliability support to engineering and program management.

In the design of electronic systems, technical and quasi-technical methods of reliability engineering are used to achieve the desired reliability objective in a timely and economical manner. Figure 3 presents some of these reliability engineering and assurance techniques that are being implemented using a digital computer to a great extent.

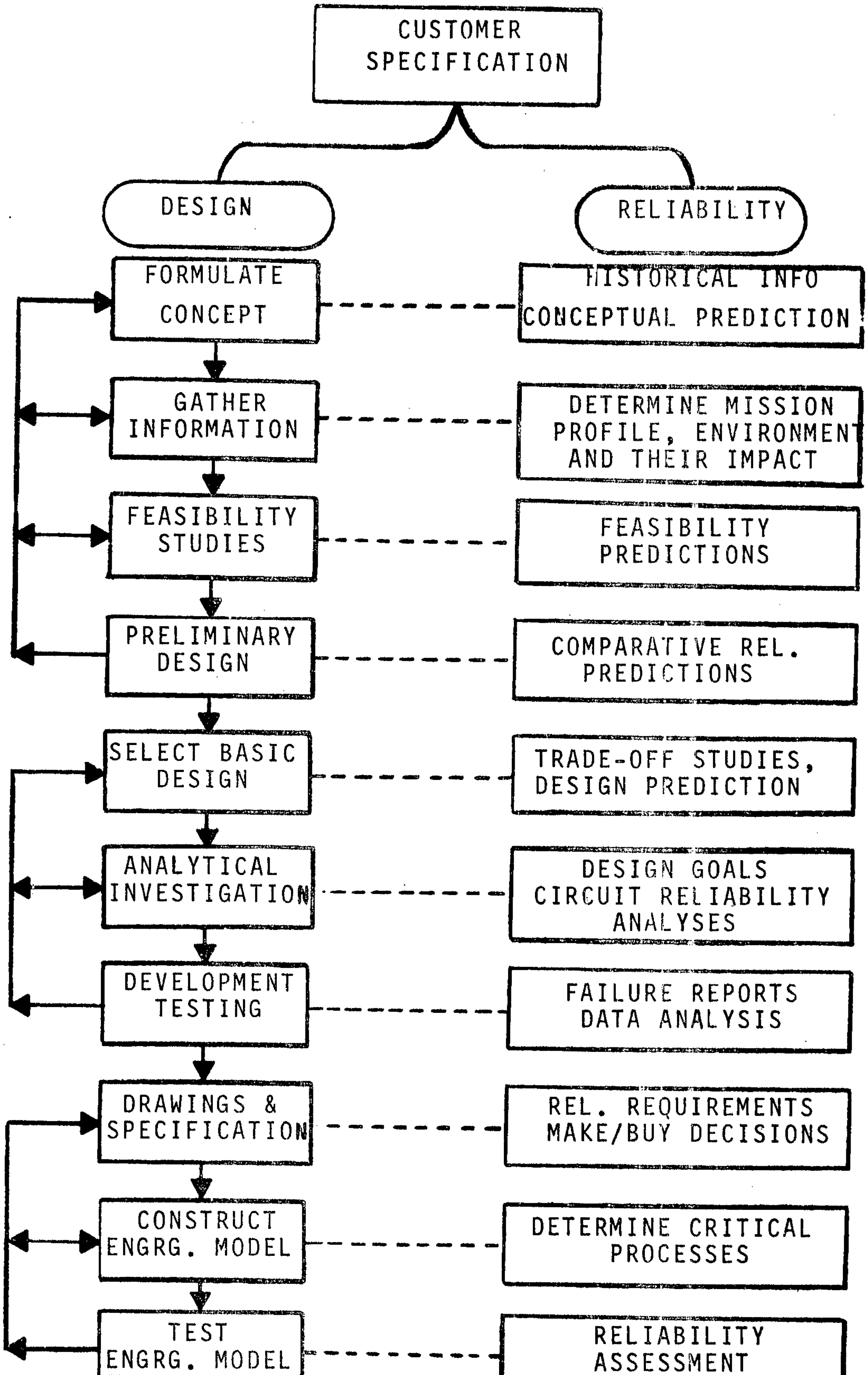


Figure 1. General Flow Chart-Design and Development Program with Reliability Support

RELIABILITY TECHNIQUES IN DESIGN & DEVELOPMENT

- DERATING/SAFETY MARGIN ANALYSIS
- FAILURE RATE PREDICTION
- FAILURE MODE & EFFECTS ANALYSIS
- REDUNDANCY IN DESIGN
- FAIL-SAFE PROTECTION
- CALENDAR/OPERATING LIFE STUDIES
- MISSION RELIABILITY ANALYSIS
- CIRCUIT RELIABILITY ANALYSES
- DESIGN RELIABILITY REVIEW
- FAILURE ANALYSIS
- PARTS RELIABILITY PROGRAMS
- RELIABILITY TESTING

Figure 2. Reliability Techniques in Design and Development

COMPUTER-AIDED RELIABILITY ENGINEERING TECHNIQUES

- STRESS ANALYSIS
- DERATING ANALYSIS
- FAILURE RATE PREDICTION
  - QUICK (FEASIBILITY)
  - STRESS-BASED (DESIGN)
- RELIABILITY/CRITICALITY ANALYSIS
- FAILURE MODES & EFFECTS ANALYSIS
- MONTE-CARLO TOLERANCE ANALYSIS
- WORST CASE (EOL) ANALYSIS

COMPUTER-AIDED RELIABILITY ASSURANCE TECHNIQUES

- FAILURE REPORT DATA SUMMARY
- FAILURE ANALYSIS DATA & STATUS INFO.
- OPERATING TIME/CYCLE DATA

Figure 3. Computer-Aided Reliability Techniques

STRESS/DERATING ANALYSIS

The need for conducting an analysis of applied electrical stresses on the constituent parts of electrical circuits is twofold. First, it provides assurance that parts are not exposed to electrical stresses in excess of their recommended maximum ratings. If additional safety margin limitations are imposed above the specification constraints, the stress analysis exercise provides an indication of the extent of compliance to derating guidelines. The second reason for analyzing part stresses is to obtain the necessary stress data required to perform a failure rate prediction. Such a method is detailed in paragraph 5.0 of MIL-HDBK-217A.

Figure 4 shows the headings of a typical manually prepared "stress sheet." As can be seen from the requirements of the data columns, the complete worksheet contains a great deal of useful information. It represents much toil as a necessary adjunct to obtaining a high level of formalized confidence in the design's reliability. It wasn't long before management realized that the manpower spent in manually processing "stress sheets" could be better utilized in other reliability tasks.

A new approach uses a digital computer to aid in the stress and safety margin calculations, derating verification, and failure rate determination and summation. There are, of course, many advantages to a computer-aided reliability analysis such as:

1. Speed of Computations
2. Reliable Computations
3. Documented Output
4. Ease of Update
5. Lower Cost

"BALL-PARK" PREDICTION

The total reliability approach I have taken is based on the concept that reliability is a measurable product characteristic that must be initiated during design and assured during production in order to be achieved in use. The reliability engineering program should be integrated into the normal development and design phase for electronic equipment. The techniques discussed here are considered effective reliability methods, inasmuch as they achieve a satisfactory level of reliability and usually comply with customer specifications (MIL-STD-785, NPC 250-1, MIL-R-22732 etc.). The judicious selection of an appropriate technique or combinations of techniques is influenced by the reliability state of the equipment as well as the particular stage in the product's design cycle. For example, during the conceptual stage, when detailed design information is not yet available, the "ball-park" prediction techniques (of which there are many) provide a reasonable approach to estimating anticipated reliability.

In documents, such as MIL-HDBK-217A, there are several methods of reliability prediction. For purposes of illustration let us

STRESS SHEET DATA

- SCHEMATIC REFERENCE SYMBOL
- PART TECHNICAL DESCRIPTION
- PART NUMBER
- SPECIFICATION NUMBER
- MANUFACTURER
- NORMAL RATING
- MAX. RATED AMB. TEMPERATURE
- MAX. DESIGN AMB. TEMPERATURE
- DERATING FACTORS
- MAX. STRESS ALLOWED
- MAX. STRESS APPLIED
- SAFETY FACTOR
- AVG. OPERATING STRESS
- APPLIED/RATED STRESS RATIO

Figure 4. Stress Sheet Data

refer to these and in particular to the "standard" methods of MIL-STD-756 (Reliability Prediction). In MIL-STD-756, the "ball-park" method is known as the feasibility prediction and is a procedure for predicting reliability when design is newborn. Admittedly, situations arise where one has no alternative and must use such a method as an "educated guestimate". Another recourse is to draw analogies to known reliability numerics of similar equipments.

The other MIL-STD-756 prediction method is the design prediction procedure. This approach is also known as the stress-based prediction technique wherein an electrical and thermal stress analysis is a prerequisite to obtaining stress-based failure rates. This form of prediction to be effective must await the release of design particulars. With recent improvements in failure rate data availability through such programs as the Navy administered tri-service and NASA sponsored FARADA (FAilure RAte DAta) program, this prediction technique is gaining the widest acceptance as the method giving the most valid results.

A small problem may arise in reconciling the ball-park prediction with the stress-based design prediction when there exists a relatively good definition of the design configuration in terms of parts assemblage. It has been my observation that unless you have opportunities for comparing ball-park estimating with stress-based predictions and demonstrated reliability, you are likely to encounter difficulty in defending its veracity.

It has sometimes been advantageous to perform a quasi-stress-based design prediction. Such a modified approach presumes that an average stress level can be predicted for each class and style of part. With experience, a reliability engineer can closely anticipate the applied stresses within some bounds and by applying a bit of conservatism and common sense (engineering judgment) can arrive at a forecasted value of reliability that will be close to the final stress-based design prediction.

A method has been devised at Bell Aerosystems to aid in performing credible failure rate (and MTBF) predictions for pre-design activities, such as tradeoff studies and proposals. This program, called QUICK, provides failure rate predictions based on generalized design information and eliminates the tedious and time-consuming effort associated with predictions of large complex hardware systems. A computer-aided reliability prediction technique was developed to exploit the data handling and rapid turn-around ability of a large digital computer (such as the IBM-360/65). This feasibility-type prediction routine couples the data tables of MIL-HDBK-217 with the intuitiveness and ingenuity of the reliability engineer in closing the "credibility gap" that exists in "ball-park" predictions. This technique consists essentially of compilations of part failure rates determined for a specified electrical stress level and for one or more thermal stress levels. This latter point is important when the

exact ambient temperature is not known and several values within the expected range can be programmed into the prediction.

There also arise occasions when a worst case prediction is desirable. This is accomplished by prescribing worst case electrical stress levels (experience factor) and the maximum specified ambient temperature condition with an additional adjustment for internal heat rise. During a single pass through the computer up to six different package temperatures can be used, the computer providing sufficient points to define an MTBF versus temperature curve for the equipment under consideration. In the QUICK program, a serial reliability relationship is assumed among all parts of a circuit and among circuits in the next higher assembly or system. A three-temperature output of QUICK is shown as Figure 5.

DESIGN PREDICTION

Since 1958 the industry has been analyzing stress factors on electronic parts as a prerequisite to predicting electronic equipment reliability. This required a lot of data research to obtain rating information and a great deal of manual calculations and information recording. From 1966 the computed-aided approach has accomplished essentially the same analysis more efficiently at less cost.

In general, where the firm details of the design are known, the most widely used prediction method throughout the aerospace and electronics industries is based on some form of stress analysis. Calculated or measured electrical and thermal stresses are compiled and used to determine an applicable failure rate from failure rate versus stress tables in MIL-HDBK-217A. While much criticism has been leveled against the validity of many of these data, it has generally been recognized that the basic approach is sound and steps are being taken to establish a defined data base and revise the data tables; e.g. MIL-HDBK-217B.

Perhaps one aspect of the stress-analysis failure rate prediction that deserves mention is the built-in derating analysis. Each circuit part is checked for its maximum rating. A derating factor to compensate for local temperature conditions (ambient or case temperatures) is applied to assess safety margins between the applied stress level and the recommended derated level. It has proven advantageous to evaluate the maximum or worst case electrical stress regardless of duty cycle effects even though the average operating-to-rated stress ratio is the base used for deriving the failure rate. A worst case failure rate estimate is often useful in appraising the upper bound failure rate.

The failure rates of electronic parts in a benign laboratory environment are expected to be less than those of the same parts exposed to the rigors of a harsh environment. The use of correlation or application factors (commonly known as K, K_A, or π_E) attempts to adjust the laboratory-based failure rates for the application environment based on the premise that each part type

CASE NO.2 6009-702220 9/12/67

APPLICATION ENVIRONMENT - FIXED GROUND

PART SUMMARY				FAILURE RATES (FAILURES PER MILLION HOURS)		
PART TYPE	SPECIFICATION	STRESS	QTY.	TEMPERATURES (IN DEGREES CENTIGRADE) 35.	50.	65.
RESISTOR,FIXED CARBON COMPOSITION	MIL-R-11	0.30	12	0.25200	0.25200	0.46080
DIODE,SILICON OVER 1 WATT	MIL-S-19500	0.20	11	1.10000	1.10000	1.76000
DIODE,ZENER	MIL-S-19500	0.10	2	1.04667	1.40667	1.81333
TRANSISTOR,SILICON NPN,1 WATT OR LESS	MIL-S-19500	0.20	2	0.83500	1.33000	1.93000
POWER SUPPLY	6009-70253-1	N/A	1	14.30000	14.30000	14.30000
POWER SUPPLY	6009-70254-1	N/A	1	14.30000	14.30000	14.30000
CIRCUIT BREAKER	6009-702967	N/A	1	0.50000	0.50000	0.50000
TRANSFORMER	6009-702987-1	1	0	0.34000	0.10000	0.10000
SWITCH-TOGGLE	6009-702951-1	N/A	1	0.10000	0.10000	0.10000
FILTER	JN17-35214	N/A	2	0.70000	0.70000	0.70000
RELAY	6009-702969-1	N/A	2	0.06400	0.06400	0.06400
LIGHT-INDICATOR	NONE	N/A	2	5.34000	5.34000	5.34000
RECEPTACLE	NONE	N/A	3	0.33000	0.33000	0.33000
CONNECTOR	MS3122E16-26S	N/A	1	0.06000	0.06000	0.06000
CONNECTOR	MS3122E12-3P	N/A	1	0.01000	0.01000	0.01000
TEST JACK	NONE	N/A	5	0.20000	0.20000	0.20000
SOLDER CONNECTION	NONE	N/A	150	0.07500	0.07500	0.07500
		TOTAL FAILURE RATE		39.25266	40.16766	42.04313
		MTBF (IN HOURS)		25476	24896	23785

Figure 5. QUICK Output

is affected differently by the same environmental stresses, i.e. failure mechanisms are unique to each generic part type. The entire rationale of the design prediction procedure is aimed at getting from the paper design to a projection of expected field reliability by using known and anticipated effects of stresses and environments.

This program, written for use on the IBM 360/65 computer, is known by the acronym CASE (Computer Aided Stress Evaluation). CASE provides a method for computing failure rates and MTBFs of circuits based on the assumption of a serial reliability relationship among the constituent electronic parts with additive failure rates. It uses MIL-HDBK-217A as the primary failure rate data source with provisions for adding failure rate versus stress tables (curves) from alternate sources. Temperature limits, electrical ratings and derating factors are stored on tape for the most commonly used styles of military specification grade parts for which failure rates are available in MIL-HDBK-217A. Figure 6 is a hypothetical circuit output from CASE showing several styles of parts. A major advantage of the program is the ease of handling changes when in a dynamic design situation. New cards are made for the affected parts or circuits and combined with the basic deck bringing the circuit prediction quickly up to date.

FAILURE MODES AND EFFECTS ANALYSIS

Before reliability improvements can be incorporated into any equipment, deficiencies which represent potential failures must be overcome. Reducing the probability that a part or circuit may fail catastrophically or degrade beyond its useful limits will increase reliability. One of the most effective approaches to accomplishing this is the Failure Modes and Effects Analysis (FMEA).

In an FMEA all potential failure mechanisms of the equipment's constituent elements, parts or circuits are determined and their corresponding effect on equipment performance examined as they affect reliability. A review of these possible failure modes is made under various functional environments and operating conditions.

The first part of FMEA is a qualitative analysis considering only the electrical and physical phenomena associated with each hypothetical failure. The second part of FMEA is a quantitative attempt to numerically assess the modes of failure and their effect on mission success. This weighted evaluation operates on the known failure rate numeric λ and the not-so-well known failure mode probability Pr to establish the FMEA term of modal failure rate $\lambda m \approx Pr\, \lambda$, i.e., the relative frequency with which an item fails in a particular mode. The primary benefit of FMEA is in spot-lighting areas of design where additional safety margins, environmental constraints and isolation, material changes or specialized testing need to be imposed to inhibit or circumvent a particular failure mode. FMEA systematically examines the basic

CIRCUIT NUMBER 1 SWITCH DRIVER 03/29/68

RELIABILITY DERATING FACTOR = 1.0000

AVE (MAX) AMBIENT TEMPERATURE = 40.0 (77.0) DEGREES CENTIGRADE

APPLICATION ENVIRONMENT - MISSILE

REF	PART DESCRIPTION	PART NUMBER AND SPECIFICATION	NORMAL RATING	MAX RATED TEMP.	MAX STRESS ALLOWED	MAX STRESS APPLIED	AVE STRESS APPLIED	SAFETY FACTOR	STRESS RATIO	BASE FAILURE RATE	ADJUSTED FAILURE RATE
R1	RESISTOR, FIXED CARBON COMPOSITION	RC07G153J MIL-R-11	0.25	155.	0.23	0.001	0.001	10.00	0.00	0.00350	0.17500
R2	RESISTOR, FIXED FILM INSULATED	M22684/01-0015 MIL-R-22684	0.25	125.	0.22	0.040	0.040	5.45	0.16	0.17600	1.40800
R3	RESISTOR, FIXED FILM,ER LEVEL S	RNR55C6650FS MIL-R-55182	0.10	175.	0.10	0.020	0.018	5.00	0.18	0.00190	0.00190
C1	CAPACITOR, FIXED CORNING GLASS 300V	CYFR-15G122J SPEC-J-951	300.00	125.	300.00	19.000	19.000	10.00	0.06	0.00010	0.00600
C2	CAPACITOR, FIXED TANT. ER. LEVEL P	M39003/01-2608 MIL-C-39003	50.00	125.	50.00	22.000	22.000	2.27	0.44	0.02860	0.02860
C3	CAPACITOR, FIXED CERAMIC TEMP. 125	CKR12BX102KM MIL-C-39014	100.00	125.	100.00	5.000	2.500	10.00	0.02	0.00200	0.03000
CR1	DIODE, ZENER	TX1N758A MIL-S-19500	0.40	175.	0.31	0.146	0.140	2.15	0.27	0.71000	0.71000
Q1	TRANSISTOR, SIL. NPN OVER 1 WATT	2N2034 MIL-S-19500	8.75	200.	6.15	0.350	0.232	10.00	0.11	0.29223	21.91713
Q2	TRANSISTOR, SIL. NPN 1 WATT OR LESS	2N2453A MIL-S-19500	0.30	200.	0.21	0.010	0.001	10.00	0.09	0.13518	3.37952
IC1	INTEGRATED CIRCUIT TEXAS INSTRUMENTS	SN523A NONE	NA	125	NA	NA	NA	NA	NA	0.40000	0.22000

TOTAL FAILURE RATE (PER MILLION HOURS)

BASE = 1.74951 ADJUSTED = 27.87611

TOTAL MEAN TIME BETWEEN FAILURES 35873

Figure 6. CASE Output

causes of equipment failure early in the design stage to minimize their actual occurrence and approach fail-safe designs. FMEA is a very valuable addition to the inventory of reliability engineering techniques and one which sees frequent service. It can be applied at several levels of the design, namely to part, circuit, assembly, component, subsystem and system levels.

The procedural guidelines for any level are generally the same. Using a functional schematic diagram, a worksheet and data sources for failure rates and modes, the reliability engineer determines the dependency or independency of each design element and the "how" and "how often" a part can fail. FMEA's are usually conducted at nominal operating conditions but may be considered at various degrees of environmental and functional conditions to include even the comparatively rare occurring modes of failure. By weighting the failure modes and effects, a ranking of effects is readily achieved which provides an initial order of attack to improve product reliability. For a low to medium complex system, FMEA is employed from the circuit part level upwards. This means that initially the predominant failure modes of the constituent parts of a circuit are examined with respect to their effect on adjacent parts and circuit performance. Here again, an opportunity presents itself to reduce the tedium and duration of the analysis by computerizing the mathematical calculations.

It should be apparent by now that computer-aided reliability techniques are very valuable to the reliability engineer. They make the task easier and eliminate time consuming routine with the result that the task may be accomplished in a timely manner. Of equal importance, the manhours saved on such efforts constitute cost savings or may be applied profitably to other reliability tasks.

A computer-aided program has been developed to organize and compute the FMEA known as FMECA or Failure Modes, Effects, and Criticality Analysis. FMECA provides a method for combining electronic part failure rates into functional modal failure rates at escalating levels of assembly. Electronic part failure rates are computed using the same routine as in the CASE program. The differences begin at the apportionment of these failure rates into modal failure rates based on the input of predominant failure mode probabilities Pr. All part modal failure rates which have the same effect on the circuit output are summed to provide circuit modal failure rates. In turn, those having the same effect on the next higher assembly are grouped and the rates again summed. Assembly, component and subsystem modal failure rates are then summed using the same routine to obtain system modal failure rates. Reliability figures of merit are then computed using mission phase durations and K-factors. A ranking of the unreliability factor in the order of "most critical" to "least critical" establishes a sequence of priorities for reliability corrective action. A partial FMECA output is shown in Figure 7.

ACCELEROMETER ANALOG TELEMETRY CONDITIONER DVM IIA 6073-302310 40C 01/25/68

RELIABILITY DERATING FACTOR = 0.5000

AMBIENT TEMPERATURE = 40.0 DEGREES CENTIGRADE

APPLICATION ENVIRONMENT - BASE FAILURE RATE

REF	PART DESCRIPTION	FUNCTION	FAILURE MODE	INTERNAL CIRCUIT	CIRCUIT OUTPUT	ADJUSTED FAILURE RATE	PROB.	MODAL FAILURE RATE
R1	RESISTOR, FIXED CARBON COMP. ER	COLLECTOR LOAD	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NO OUTPUT		0.010	0.00003
R2	RESISTOR, FIXED CARBON COMP. ER	TIMING	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NO OUTPUT		0.010	0.00003
R3	RESISTOR, FIXED CARBON COMP. ER	BIAS	OPEN		DEGRADED OUTPUT	0.00262	0.990	0.00260
			SHORT		NO OUTPUT		0.010	0.00003
R4	RESISTOR, FIXED CARBON COMP. ER	COLLECTOR LOAD	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NO OUTPUT		0.010	0.00003
R5	RESISTOR, FIXED CARBON COMP. ER	TIMING	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NO OUTPUT		0.010	0.00003
R6	RESISTOR, FIXED CARBON COMP. ER	BIAS	OPEN		DEGRADED OUTPUT	0.00262	0.990	0.00260
			SHORT		NO OUTPUT		0.010	0.00003
R7	RESISTOR, FIXED CARBON COMP. ER	CURRENT LIMITER	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		DEGRADED OUTPUT		0.010	0.00003
R8	RESISTOR, FIXED CARBON COMP. ER	CURRENT LIMITER	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		DEGRADED OUTPUT		0.010	0.00003
R9	RESISTOR, FIXED CARBON COMP. ER	CURRENT LIMITER	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NO EFFECT		0.010	0.00003
R10	RESISTOR, FIXED CARBON COMP. ER	CURRENT LIMITER	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NO EFFECT		0.010	0.00003
R12	RESISTOR, FIXED FILM,ER LEVEL S	VOLTAGE DIVIDER	OPEN		LOW OUTPUT	0.00190	0.990	0.00188
			SHORT		HIGH OUTPUT		0.010	0.00002
R14	RESISTOR, FIXED CARBON COMP. ER	IMPEDANCE MATCHING	OPEN		NO OUTPUT	0.00262	0.990	0.00260
			SHORT		NOISY OUTPUT		0.010	0.00003

Figure 7. FMECA Output

CIRCUIT RELIABILITY ANALYSIS

Circuit designers often follow these basic steps during preliminary design:

1. Review several circuit approaches and select one which appears to best meet performance requirements.
2. Determine the necessary dc and ac steady-state and transient responses and select the parts needed.
3. Calculate power and voltage stresses on the circuit elements selected.
4. Build a breadboard model and checkout nominal performance.
5. Perform environmental testing (normally just high and low temperature) and tolerance verification if time permits and "bogie" parts are available.

Steps 2 and 3 are an example of a minimum network analysis. Steps 4 and 5 are empirical methods employed to verify the design.

In Step 5, the designer tests the effects of tolerance changes of circuit elements to determine output parameter sensitivity and variation.

To obtain a highly satisfactory design and to insure with a reasonably high confidence that tolerance effects have been minimized, the designer must repeat his tests a number of times making changes accordingly. Thus, the design process is an iterative one whereby changes are made, the effects noted, more changes incorporated, their influences observed, design adjustments made, and so forth. These steps, of course, are easily and quickly accomplished using modern EDP methods. Figure 8 shows an information flow chart tying together the design, reliability and computer groups for computer-aided circuit reliability analyses.

The largest obstacle to wider and effective use of the computer is the lack of proper models of complex non-linear devices. A significant advantage exists over the manual design process when we obtain the proper analytical model. It has been previously pointed out, rating and derating checks can easily be accomplished by EDP methods. Once an equivalent circuit has been programmed, ac or dc steady-state analysis, and frequency and transient behavior can be determined quantitatively using one of the well known general purpose programs such as ECAP, NET-1, CIRCUS, SCEPTRE and others. These programs are not primarily reliability-oriented programs, but rather are tools to be used by all electronics engineers. Interestingly enough, it has been the reliability engineer in many of the leading aerospace companies who has recognized the tremendous potential of these programs and such has been the case at Bell Aerosystems.

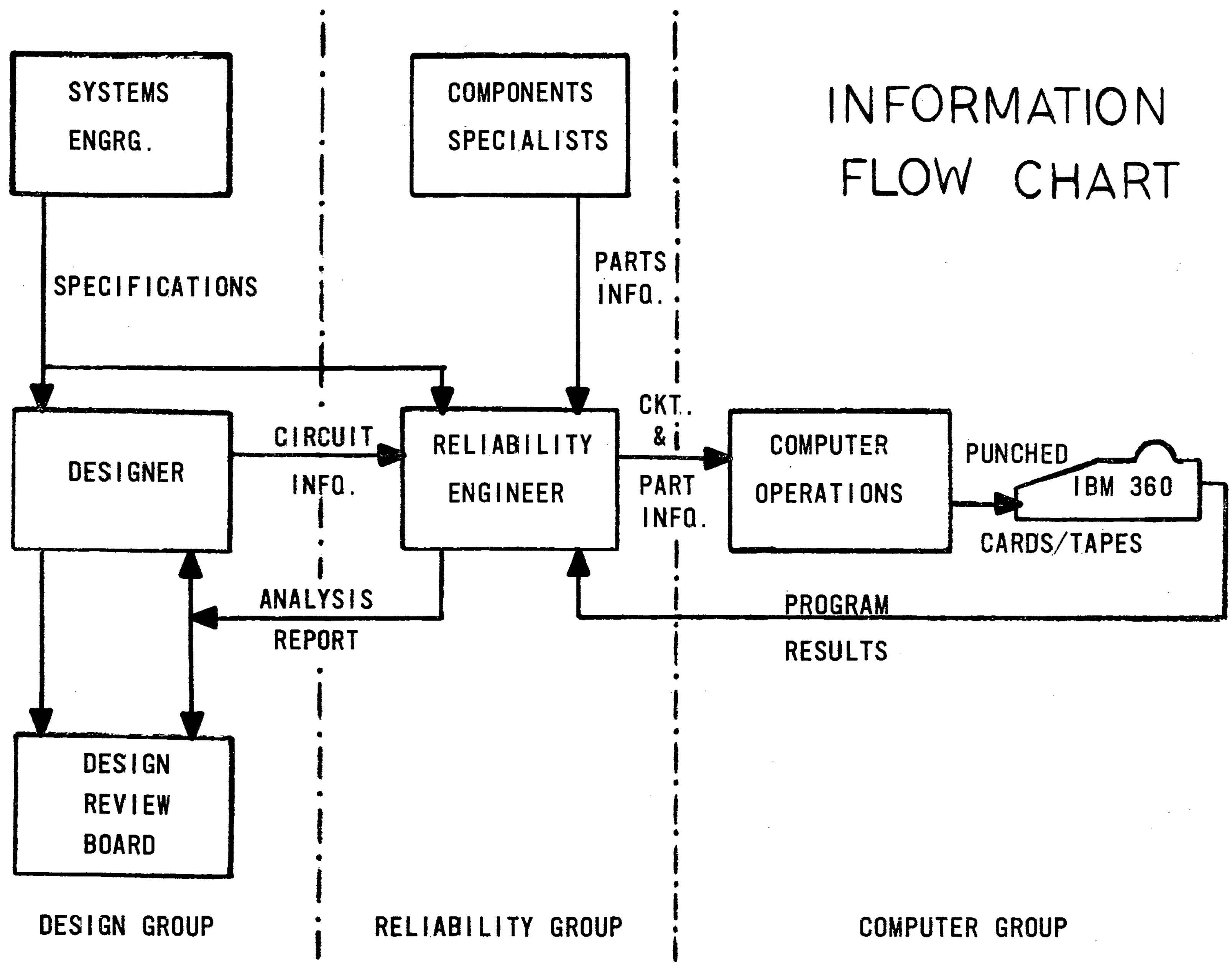


Figure 8. Information Flow Chart

Of primary concern to the reliability engineer is what I call the fifth step in the design process, tolerance analysis. This technique utilizes the methods of statistical analysis, very often the Monte-Carlo process. Using the computer, circuits can be constructed and analytically tested for thousands of combinations of tolerances and the distribution of significant parameters analyzed to effect an optimum design center. The variation of circuit element parameters can be exercised within manufacturing tolerance limits or at the end-of-life extremes to examine worst-case conditions. The selecting of tolerance limits for analysis should consider other influencing factors as shown in Figure 9. All circuit element properties can be varied randomly and simultaneously or can be held at nominal value and selected element parameters varied individually to assess circuit sensitivity and develop a classification of criticality. It is here in the area of circuit reliability analysis where in the past the reliability engineer has experienced his greatest difficulty. It is now in this area where he can make a significant contribution to the evaluation and improvement of design reliability through the recently developed computer-aided design analysis programs. The major advantages of computer-aided circuit reliability analysis are shown in Figure 10.

WORST-CASE (EOL) DESIGN ANALYSIS

In general, circuits are designed for worst-case conditions of operation. That is, they satisfy the functional requirement under the end-limits of temperature and part tolerance. The designer generally performs such an analysis himself; however, it sometimes falls to the reliability engineer to verify or even conduct the details of this analysis.

The availability of general purpose network analysis computer programs such as ECAP and PANE (both IBM developed) allows the analysis of worst-case conditions to be performed with less tedium and great speed. Worst-case analysis is a non-statistical approach to determine the worst effects, with given part tolerance end limits, on circuit performance.

The method used is to set part values and input parameters of the circuit to those extreme tolerance limits that tend to produce the maximum detrimental change in circuit output. The input data consists of a topological description of the circuit or circuit performance equation. Individual part parameters with their purchase tolerance limits or their end-of-life (EOL) limits are read in and circuit output parameters are specified. A solution is first obtained with all parameters at nominal values, then partial derivatives of each output parameter with respect to each input parameter are computed. The computer uses the sign of the partial derivative to indicate a direct (+) or inverse (-) relationship. A solution is then obtained using the worst-case limit for each part in the circuit, solving for the desired worst-case output parameter. Sensitivity analyses are accomplished by setting each part parameter, one-at-a-time, to its worst-case limit and calculating the change in the circuit performance parameter. Such a routine enables the reliability

SELECTING TOLERANCE LIMITS

1. STATE - OF - THE - ART
2. ECONOMIC CONSIDERATIONS
3. SYSTEM REQUIREMENTS
4. PRODUCTION YIELDS
5. LONG TERM STABILITY
6. ENVIRONMENTAL CONDITIONS
7. LOADING EFFECTS
8. RANDOM CHANGES

Figure 9. Selecting Tolerance Limits

C - A CIRCUIT RELIABILITY ANALYSIS

- EARLY CHECKOUT OF DESIGN
- VERIFY BREADBOARD RESULTS
- CHECK IMPROVEMENTS QUICKLY
- OPTIMIZE NOMINAL VALUES & TOLERANCES
- NEGLIGIBLE COST
- RAPID & ACCURATE RESULTS

Figure 10. C-A Circuit Reliability Analysis

engineer to classify the critical and major circuit parameters. This information is useful to the designer for selecting economic but adequately stable components for the circuit or to modify the design, if necessary, to reduce the critical effects of certain uncontrollable parameters.

MONTE-CARLO CIRCUIT RELIABILITY ANALYSIS

Through computer-aided Monte-Carlo (M-C) analysis methods, the reliability engineer can analyze the simulated performance of thousands of circuits (Figure 11) and assign statistical description to assist in reliability evaluation (Figure 12). This analysis method can be truly described as a reliability technique. The M-C method as applied to electronic circuit reliability analysis is a technique for introducing the full range of values that quantitatively describe a circuit factor such as a circuit input or an element parameter. The name is derived from the technique's similarity to gambling devices used to generate probabilistic data through unrestricted random sampling and popularly demonstrated by the use of roulette wheels or dice.

Using computer-aided M-C analysis, the reliability engineer can determine the design center and assist the designer in avoiding a "knife's-edge" design where a slight change in value causes a large degradation in performance. Using our computer output data, a histogram shows us a figure of reliability from a non-catastrophic point of view. By the simple repeated selection of random combinations of circuit parameters, a valuable indication of a system's reliability is obtained. For high-quantity production runs, M-C analysis is a necessity. For the one-of-a-kind custom built programs that typify our space hardware, M-C can simulate thousands of cases of potential degradation which the cost of fabrication and testing would prohibit. M-C analysis is very rarely performed by the circuit designer because of the dismal prospect of computing circuit equations through manual means.

We must do more than tell our designers and managers that the design has low MTBF. We must tell them how to improve it. We must show them which circuits border on the performance "twilight zone" and tell them through sensitivity analysis which parts are the primary culprits.

ON-LINE ANALYSIS

At the dispostion of the reliability engineer at Bell Aerosystems are 18 Remote Access Computer (RAX) Terminals connected to an IBM 360/50. These on-line typewriter-type terminals are placed at various locations throughout the engineering areas. Long distance remote computing is accomplished via telephone lines to the central processor. The larger programs such as those described earlier are handled by batch processing. The time-sharing remote terminals are used for "ball-park" type predictions and solving comparatively simple engineering problems. For example, the reliability model shown in Figure 13 has been derived

DISTRIBUTION OF PERFORMANCE PARAMETER V5 FOR 2500 CASES TESTED

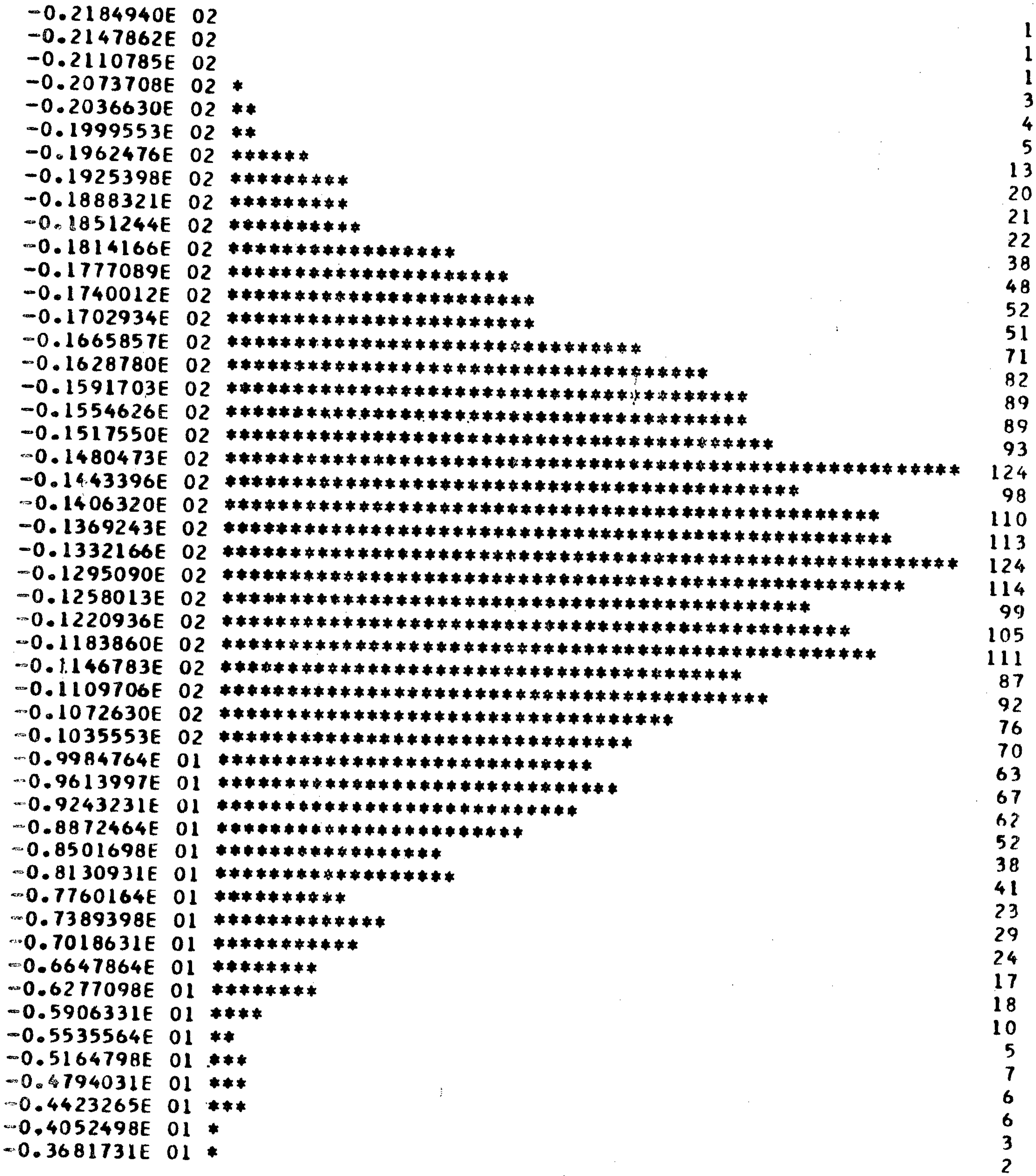
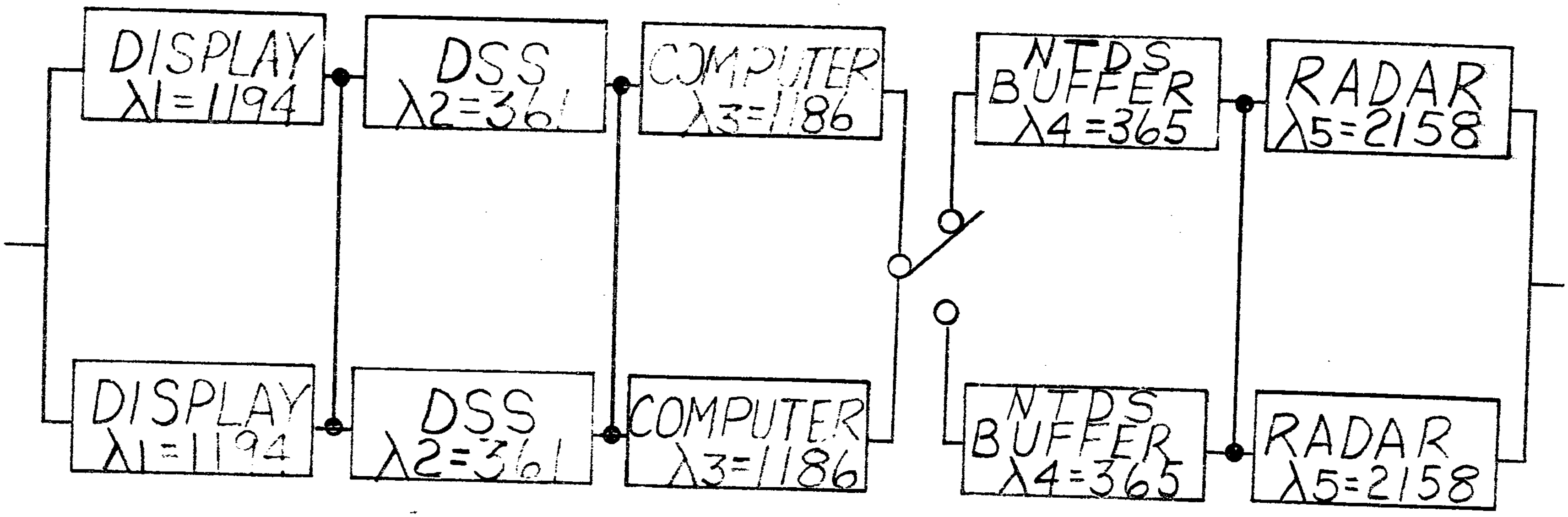


Figure 11. Monte-Carlo Output Histogram

STATISTICAL PARAMETER VARIATIONS FOR 2500 CIRCUITS TESTED

PARAMETER	MINIMUM	MEAN	MAXIMUM	NOMINAL	STD. DEV.
V1	-9.872E 00	-9.215E 00	-8.569E 00	-9.206E 00	2.650E-01
V2	-1.027E 01	-6.498E 00	-3.121E 00	-6.608E 00	1.216E 00
V3	-1.060E 01	-9.866E 00	-9.184E 00	-9.856E 00	2.753E-01
V4	-9.585E 00	-5.776E 00	-2.333E 00	-5.885E 00	1.217E 00
V5	-2.185E 01	-1.304E 01	-3.675E 00	-1.274E 01	3.152E 00
IC3	2.152E 00	2.499E 00	2.877E 00	2.499E 00	1.322E-01
IE1	1.020E 00	1.103E 00	1.194E 00	1.103E 00	3.618E-02
IE2	1.129E 00	2.889E 00	4.670E 00	2.943E 00	6.134E-01
IE3	2.174E 00	2.512E 00	2.892E 00	2.513E 00	1.329E-01

Figure 12. Monte-Carlo Statistical Parameter Variations



$$R4 = \left[(1+\lambda_4 t)e^{-\lambda_4 t}\right]\left[2e^{-\lambda_1 t} - e^{2\lambda_1 t}\right]\left[2e^{-\lambda_2 t} - e^{-2\lambda_2 t}\right] \times$$

$$\left[2e^{-\lambda_3 t} - e^{-2\lambda_3 t}\right]\left[2e^{-\lambda_5 t} - e^{-2\lambda_5 t}\right]$$

Figure 13. Reliability Model

for the dual-channel Automatic Carrier Landing System AN/SPN-42. It represents a reliability model with cross-channel operation where only one channel is required for mission success. A single manual solution of this reliability function requires about an hour of computation time. Using the RAX terminal, the reliability engineer was able to obtain 210 solutions; 42 solutions each for five different models (Figure 14) taking less than one minute of computer execution time. The start-from-scratch programming by the reliability engineer took about three hours.

THE IMPACT ON ENGINEERING

The virtual explosion of computer-aided design analysis methods applied to electronics designs has added a new dimension of analytical capability to the evaluation engineer. The "shock waves" have been felt in reliability and the reaction, naturally, to most new and strange things is one of suspicion, caution, and confusion. If you're not presently familiar with any of these techniques, sit down and talk with people in the computer programming field, find out if they know what's going on and if they can help you. Search the literature. In the leading electronic design journals and magazines, computer-aided design and analysis has been a "hot item" for the last few years. Consult the references in these articles for more information. Discuss this topic in your professional organizations among your colleagues. Realistically evaluate application to your projects. Above all, get involved now and avoid technical obsolescence later.

RELATIONSHIP WITH DESIGN

Reliability engineers can take a great step forward in overcoming much of the criticism levied against them in recent years over the widening gulf between reliability and the designer. Strained relationships with the designer must be overcome for the reliability engineer to make his contribution to the project and these powerful tools will help. Of course, as has often been said, the reliability engineer must be tough-skinned. Tact and diplomacy with firmness are necessary attributes as well, but discretion in application of reliability techniques must always be practiced. Remember, they are means and not ends. Let us not lose sight of our goals by only expanding and sophisticating our efforts. As reliability engineers, our primary function is to apply our specialized knowledge to contribute toward the creation and control of product reliability. Today, reliability engineers are better equipped to provide rapid and timely inputs to the design decision-making processes. It must be remembered that design decisions are made by engineers. The computer is a tool not a decision making device. It cannot think independently and its output depends solely upon the engineer's input.

We have learned that when communication between reliability and design groups is in the language of the statistician or in jargon unique to reliability, design understanding often breaks down. Hopefully, the practice of computer-aided design and reliability

R1 = SINGLE CHANNEL(NON-REDUNDANT)
R2 = SINGLE CHANNEL(REDUNDANT NTDS BUFFER)
R3 = DUAL CHANNEL(ONLY ONE CHANNEL REQUIRED)
R4 = DUAL CHANNEL(ONLY ONE CHANNEL REQUIRED-CROSS CHANNEL OPERATION)
R5 = DUAL CHANNEL(BOTH CHANNELS REQUIRED)

MISSION TIME-HRS	R1	R2	R3	R4	R5
0	1.0000000	1.0000000	1.0000000	1.0000000	1.0000000
1	0.9948792	0.9952423	0.9999872	0.9999923	0.9933168
2	0.9897845	0.9905071	0.9999490	0.9999694	0.9866752
3	0.9847160	0.9857943	0.9998855	0.9999312	0.9800748
4	0.9796734	0.9811038	0.9997971	0.9998779	0.9735155
5	0.9746567	0.9764354	0.9996839	0.9998095	0.9669970
6	0.9696656	0.9717892	0.9995462	0.9997262	0.9605192
7	0.9647001	0.9671649	0.9993842	0.9996280	0.9540817
8	0.9597600	0.9625625	0.9991982	0.9995150	0.9476844
9	0.9548452	0.9579819	0.9989884	0.9993873	0.9413271
10	0.9499556	0.9534230	0.9987549	0.9992449	0.9350095
11	0.9450911	0.9488856	0.9984980	0.9990879	0.9287314
12	0.9402514	0.9443697	0.9982180	0.9989165	0.9224926
13	0.9354365	0.9398752	0.9979151	0.9987307	0.9162929
14	0.9306463	0.9354019	0.9975894	0.9985306	0.9101320
15	0.9258806	0.9309498	0.9972412	0.9983162	0.9040098
16	0.9211393	0.9265188	0.9968708	0.9980876	0.8979261
17	0.9164223	0.9221087	0.9964783	0.9978450	0.8918805
18	0.9117294	0.9177195	0.9960639	0.9975884	0.8858730
19	0.9070606	0.9133511	0.9956279	0.9973179	0.8799033
20	0.9024157	0.9090033	0.9951704	0.9970336	0.8739712
21	0.8977946	0.9046762	0.9946918	0.9967355	0.8680764
22	0.8931971	0.9003695	0.9941921	0.9964237	0.8622189
23	0.8886232	0.8960832	0.9936716	0.9960983	0.8563982
24	0.8840727	0.8918172	0.9931305	0.9957594	0.8506144
30	0.8572549	0.8666418	0.9894631	0.9934470	0.8166717
40	0.8143541	0.8262437	0.9818364	0.9885657	0.7629063
50	0.7736003	0.7877185	0.9724816	0.9824694	0.7124789
60	0.7348859	0.7509799	0.9615780	0.9752367	0.6652019
70	0.6981090	0.7159457	0.9492930	0.9669449	0.6208965
80	0.6631726	0.6825373	0.9357832	0.9576695	0.5793919
90	0.6299846	0.6506796	0.9211947	0.9474845	0.5405258
100	0.5984574	0.6203011	0.9056633	0.9364616	0.5041434
110	0.5685080	0.5913336	0.8893150	0.9246705	0.4700980
120	0.5400573	0.5637119	0.8722669	0.9121786	0.4382502
130	0.5130305	0.5373738	0.8546273	0.8990508	0.4084679
140	0.4873562	0.5122601	0.8364961	0.8853499	0.3806260
150	0.4629668	0.4883142	0.8179655	0.8711360	0.3546060
160	0.4397979	0.4654821	0.7991203	0.8564665	0.3302960
170	0.4177885	0.4437123	0.7800384	0.8413966	0.3075900
180	0.3968806	0.4229556	0.7607910	0.8259787	0.2863882
190	0.3770189	0.4031652	0.7414432	0.8102628	0.2665963
200	0.3581512	0.3842963	0.7220543	0.7942962	0.2481254

Figure 14. Remote Access Computer (RAX) Output

analysis will help overcome these language barriers. The reliability engineer must better understand the design and be compelled to lean in that direction. The designer, faced with the problems of immediacy, increasingly complex and costly designs and in finding ways to reduce his creative design time, is exploring the use of computer-aided design and analytical techniques. Machine language is not necessarily the common language that will create better bonds. However, as both the designer and the reliability engineer lean more frequently toward the computer as an engineering tool, hopefully a better understanding of each other's objectives and problems will be achieved.

PROGRESSING TECHNOLOGY

There are new skills to be learned and old ones to be refurbished. Circuit theory and modeling, Fortran computer language, and electronic data processing are but a few. The large capacity digital computer offers many unexplored possibilities to the reliability engineer for solving design reliability problems.

We are on the threshold of a new era in electronics design - the age of microelectronics. In the next decade, the use of these devices will increase dramatically. Decisions must be made early to freeze the circuit design and make the production masks. The burden of attaining optimum reliability can be significantly relieved by the use of computer-aided techniques. I cannot emphasize enough that while the computer technique is a major improvement over the classical manual methods, new technologies must be mastered and new obstacles overcome. As I have pointed out, models of physical devices, especially the non-linear devices are woefully in short supply. Even where general models are available, the parametric data for individual devices are not available and reasonable approximations must be substituted. The lack of device data is due largely to the absence of a requirement for this data prior to the development of computer-aided design programs.

The data gap that haunted reliability engineers in the fifties and early sixties continues to crop up in our attempt to advance the state-of-the-reliability-art. There are presently several organized efforts to solve the major problems of using computers for design analysis. I am confident, that based on results achieved thus far, that these will be the standard tools of the reliability engineer in the seventies.

A source of major difficulty in the performance of the reliability engineer's function often arises in the interface with the design engineer. It is fundamental to circuit design to check ratings and compute stresses within the circuit and these data should be readily available from the designer. While this is true in most cases, there are individuals who do not always adequately document their findings.

The mandatory use of standard stress analysis data sheets helps. However, there are many times when the entries are questionable and

must be verified independently. The use of computer-aided design analysis programs has simplified the entire stress analysis function and has provided so many secondary benefits to designers that their full cooperation is now a way of life. At present, these techniques are being applied selectively on what we think are the critical circuits in the design. In some high-reliability aerospace applications, each circuit in the design has been subjected to at least one of the many computer-aided analyses.

In the near future, the design engineer will be designing circuits on-line with the digital computer in real time using remote terminals with light pen-CRT graphical inputs. The reliability engineer, to be an effective member of the design team, must be aware of the advances in modern engineering design and analysis. He must master these and improve his reliability skills to provide a significant contribution to electronic design reliability. The responsibility to act discretely is ever with us and the trap of putting every potential design problem on the computer must be guarded against. Don't throw away your handbooks, slide rules and desk calculators because they'll still be needed.

RADC RELIABILITY ACTIVITY -- PAST, PRESENT, AND FUTURE

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ABSTRACT:

The Rome Air Development Center (RADC) has been at the forefront of military reliability activity since the mid-1950's. In addition to its pioneering work in equipment and system reliability design, measurement, prediction, and demonstration, the last several years have seen many RADC accomplishments in the reliability of microelectronics, including the establishment of reliability physics as an important technical discipline, and the issuance of the first military standard (MIL-STD-883) designed to provide uniform methods and procedures for testing microelectronic devices.

Current and future activity will emphasize development of techniques to reduce the time and cost associated with equipment/system reliability demonstration, and, in the microelectronics area, solution of reliability problems associated with large scale microcircuit arrays.

SYNOPSIS

"SOME INTERNATIONAL ASPECTS OF RELIABILITY AND QUALITY"

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The more interesting international activities in reliability and quality are reviewed. Two kinds of organizations are mentioned: those who are international in operation with formal representation from selected countries and those who are national but whose influence is international by reason of tradition, or technical excellence. International symposiums sponsored by either category are mentioned.

The formally constituted groups most active in this area are I.E.C., NATO, AOSM, EOQC, ISA.

The influential national groups are U.S. D.O.D., B.S.I., JUSE, ASQC, and MEL.

Most groups in either category have broader responsibilities than reliability and quality and some are more oriented to quality. International standards activity may have a bearing on both.

There appears to be much common philosophy and objectives but wide variations in emphasis and methods. In general there is a trend towards raising reliability and quality levels.

The effect of common national program actions on military alliances is well established. The influence on industrial firms particularly those seeking export markets, includes a need to take more flexible approaches to meet differing requirements; more formally documented and visible programs to instill customer confidence; more effective field reporting system to improve design judgements; more attention to foreign standards in other areas bearing on reliability and quality; expanded company interest and participation in the activities of international groups.

In less sophisticated nations training and education of customer's technical personnel in reliability and maintenance practices may be essential.

ECONOMICAL RELIABILITY PROGRAM DESIGN *

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Summary

Semiconductor reliability programs can be used to evaluate products, to determine design margins, to set specification limits, to evaluate process changes, and to determine the extent and types of programs for control of product families. This paper emphasizes the need for careful experimental design in order to meet program objectives in an economical manner. Program design elements such as parameter measurements, control of the measurements, types of stress tests, levels of stress, and some of the techniques of analyzing the data to be generated are described. Several precautions to be used in generating and handling the data are also indicated.

The goals of reliability evaluations are discussed, and a comparison program is developed which could be utilized by a manufacturer to assess the effects of a proposed process change or by a user to aid in determining which of competing types of devices to purchase. The design example makes use of step-stress tests to obtain the results in a short time. There are other uses for step-stress testing, and these are outlined with some of the assumptions that are made when these tests are used.

Stress tests which have been found to be effective in revealing failure mechanisms are then combined in the design of a complex reliability program. Constant stress-in-time tests are employed and some of the assumptions in using these tests are also described. The use of device response modeling techniques such as the Weibull and Arrhenius models are discussed in the concluding portions of the paper.

Introduction

Semiconductor reliability evaluation programs have been conducted by many different organizations for many different reasons. The results of these programs have been used to determine ratings, to set design margins, to determine which of several competing products to specify, to accept lots, and many other purposes. The one common element has been that an evaluation of some form was conducted, from a simple check of electrical parameters to a large scale physics of failure program. As the performance of semiconductors improved, the costs of evaluating the performance increased since many of the failure mechanisms were reduced or eliminated. This resulted in the use of larger sample sizes and longer test times to produce failures. The most effective way to conduct an economical reliability program is to make certain that the experimental design of the program is carefully done. It is the intention of this paper to review the elements of program design, to show where each element is applicable, and to indicate how the results obtained may be applied.

Program Design Elements

The possible elements in a reliability program could include parameter measurements, conditions of measurement, operating life stress testing, stress test circuits, temperature storage stress testing, other forms of life testing, and mechanical and environmental testing. It must also be decided whether the stress tests are to be conducted at use levels, maximum rated levels, above maximum rated levels, at more than one level, and whether step-stress or constant stress-in-time tests, or a combination of these are to be used. Additional elements which must be factored into the program design include the time available for conducting the program, the availability of parameter and stress test equipment, the possible need for failure analysis equipment, and the time to be spent in recording, processing, storing and analyzing the data which will be generated.

The point about data collection cannot be overemphasized, since it is easy to collect data and it can be almost impossible to analyze it if some thought has not been given to the form in which it will be collected, and the technique that will be used in the analysis. For example, suppose that a program has been designed that will require the use of four different types of stresses, or four test cells, with 10 devices of each of two types in each of the test cells. Electrical parameters will be measured at the start of the stress testing, at intermediate points and at the end of the stress tests. If there are from five to ten parameters to be measured for each device, a usual number, it can be seen that it would be possible to generate from 400 to 800 data points at each of the readout times. If these were taken manually, there would be many possibilities of errors, and if keypunching was used to get the data in a form to use in a computer, there would be additional sources of error and additional time spent. Measurement equipment can often be connected to a paper tape punch, or a magnetic tape data recorder. The data obtained can be checked and then easily be put into a computer for some of the data analysis.

It is also possible to simplify the data recording process by the use of Read A and Read B

* Paper originally presented at the 1969 Annual Symposium in Chicago.

lists of parameters. The Read A list of parameters could be the entire set of interest and would be read out only at the beginning and the end of the entire program. At the intermédiate read times, the shorter set of Read B parameters would be recorded. The Read B list would contain only those few parameters which would be most likely to indicate degradation during the stress.

Electrical parameter measurements will be a part of any program, but it must be decided which parameters are to be measured, and the conditions of the measurement. The order in which the parameters are measured is important, as is the technique by which the measurement is performed. For example, the leakage currents of devices are affected by the junction temperature so that if tests are made which heat the device, such as high current beta or saturation voltage, the leakage currents must be measured first. Even in high speed automatic equipment, it is possible to heat the devices enough to raise the junction temperature. The technique by which the measurement is made should be known since it is possible for an observed degradation to be induced by the measurement equipment. For example, when a breakdown voltage is measured at some specific current, one of the common equipments actually programs a voltage supply to increase while monitoring the current and then records the voltage necessary to produce the current. If the contact to the device was intermittently open, the supply would be programmed to its maximum, or to the clamp voltage. This could be a value of 500 volts, and if the contact to the device was then made, it would be possible to apply 500 volts to a 70 volt device. The results are usually catastrophic.

This type of intermittent contact, or similar problems, can be guarded against by making certain that the built in clamping or current limiting features are operative and correctly set. It is also very useful to repeat one of the early parameter measurements, such as a low voltage leakage current, at the end of the measurement sequence. If heat has been generated, the value will be higher but it will be possible to correlate the second reading with the first. This technique was used on some large programs[1,2] and proved invaluable in demonstrating test equipment induced degradation.

Many transistor evaluation programs would only require the measurement of the leakage currents, the current gain and the saturation voltages. These parameters will usually show device degradation in a manner that can be related to the failure mechanism. In particular, there is seldom any need to monitor the dynamic parameters such as switching speed since degradation in this parameter is related to the other parameters. In a similar manner, the evaluation of a diode can be accomplished by monitoring the reverse current and the forward voltage drop. In fact, on a three year program that was conducted on the physics of failure evaluation of a signal diode[2,3] the failure mechanisms relating to both reverse and forward bias stressing were all observed and separated by analysis of the changes in the reverse current alone.

Parameter selection for an integrated circuit is a more complex process, since it is often impossible to measure the characteristics of just one of the elements of the circuit. It may be desirable to conduct a small scale exploratory program, with many parameter measurements, and then examine the results to determine which parameters provide an indication of potential degradation. The most important point to be made is that it is seldom, if ever, necessary to measure all the parameters on a specification sheet in order to conduct a reliability evaluation; and the reduction of the data to an absolute minimum is one way to reduce the cost of the program. Not only is there less time spent in taking the data, but the data analysis time is reduced. The decision of the best parameters to monitor, and the bias conditions for the measurement, require knowledge of the device being evaluated. There is not enough space here to discuss this problem, but the proceedings of the Reliability Symposium and of the Reliability Physics Symposium (formerly Physics of Failure in Electronics) contain many excellent papers on this and related subjects.

Program Design Goals

The goal of the evaluation program is used to determine the quantity and types of stress tests that will be required. The user of semiconductor devices is often interested in the comparison of two, or more, devices produced by different suppliers, to decide which of them is the best to purchase. The manufacturer is often trying to determine if a proposed process change results in a better device, or a device of the same reliability which is less expensive to produce. These two programs are really very much the same, although the manufacturer usually has to conduct his program in greater depth since the differences relating to a process change are often quite subtle, and extensive failure analysis techniques may be required.

Another large group of evaluation programs are those concerned with designing or applying lot acceptance tests. These programs are usually simpler to design since the objective is to see if the devices will meet or exceed some stipulated criteria, and there is little or no concern with the amount by which the device performance may exceed the specified value. The military specifications, such as MIL-STD-750, MIL-STD-202, MIL-S-19500, MIL-STD-883 and MIL-STD-105 describe the sampling procedures, the acceptance criteria and the measurements to be performed for most lot acceptance programs. These programs will not be discussed further, except in the discussion of determining device destruction thresholds and maximum ratings.

One of the more complex reliability evaluation programs to design is concerned with determining the failure rates of semiconductor devices. The observed failure rates, at use conditions, are quite low and many hundreds of thousands, or millions of unit hours of test are necessary to demonstrate the low failure rates. For example, for the exponential model approximately 390,000 unit hours of test time would have to be accumulated to demonstrate a failure rate of 1%/1000 hours, at a 90% confidence level and with one observed failure. Changing the confidence level to 60% reduces the unit hours of test required to about 205,000. When it is desired to demonstrate failure rates that are well below 1%/1000 hours, it is easy to see that millions of unit hours of test can be required. For this reason, these types of programs are being conducted at accelerated levels and the results are being extrapolated down to the use levels. Several of these evaluations have been conducted [1,2] and the techniques, assumptions and uses of the techniques will be described later. The amount of time available for the program also determines the type of stress tests that can be utilized, particularly in the selection of the maximum amount of time available for constant stress-in-time life testing.

Comparison Programs

One of the most common types of evaluation program designs is concerned with the comparison of the performance of two, or more, types of devices. The user may be trying to determine which of two competing devices to buy, or the manufacturer may be assessing the effects of a process improvement. The goal of this program is to compare the amount of the device response, and to obtain the responses in a short period of time. This means that the parameters which will be monitored will have to be recorded as variables data, not as being within limits (attribute or go/no go data). Step-stress testing is very useful here since the level can be increased until failures or significant responses are actually produced. It will be necessary to determine a tentative definition of failure to translate the desired circuit performance into device characteristics, but this can be quite loose at the start of the program, since the data taken will show the individual device shifts. The analysis of the data can then be used to select a more precise definition of failure at the end of the stress program.

In developing the program design for this paper, it will be assumed that the area to be investigated is the pellet surface stability. Surface instability usually results in the formation of inversion layers, or channeling. The types of stresses that will reveal the associated failure mechanisms include:

- High temperature storage,
- High temperature storage with applied bias,
- Operating power,
- Humidity cycling with applied bias,
- Humidity life.

The first three stresses are applicable to metallic encapsulated devices and all five stresses can apply to non-metallic encapsulations.

Experience indicates that high temperature storage with applied reverse bias is the most sensitive test. The High Temperature Reverse Bias, HTRB, test is not difficult to conduct, but it must be remembered that the applied bias must be left on the devices while they are being cooled to room temperature for parameter measurements. If this is not done, the inversion layers that might have been formed will be annealed out and it will be difficult to observe any response to the test.

To complete the design of the program, it is necessary to select the bias level, the temperatures and the time for each tread length, and the number of devices to be stressed. The easiest stress parameter to step is temperature, and most devices will withstand temperatures over the maximum rating better than the application of over voltage. The goal of the step-stress is to produce monotonic degradation failures rather than to have no response and then an abrupt occurrence of catastrophic failures. Since the reverse voltage-current characteristic of semiconductors softens at high temperatures, the HTRB test should be run at a voltage less than the rated voltage, and as in operating life testing, a value from 50 to 75% of the rated voltage works well. The temperature can be stepped in increments of 25°C or 50°C and stress times of 72 hours for each tread represent a convenient and reasonably short stress time. Many failure mechanisms can be revealed with even shorter stress times, but the 72 hour period provides a high level of confidence that any mechanisms present will be detected. For this type of test, the probability is high that significant performance differences in the two device types will be detected with 20 units of each type placed on stress. If five units of each type are also assigned as control units, the total quantity would then be 50 units.

The program which has been outlined is a very simple one, but the principles developed can then be used to extend the evaluation. Most evaluation engineers prefer to have life test data available and a step-stress test of operating life, with constantly increasing levels of dissipated power or constantly increasing levels of the ambient temperature can provide much useful information. However, conducting operating life tests at very high ambient temperatures can lead to some severe problems in the test cards on which the devices are mounted[4]. The requirements for failure analysis to separate legitimate and test equipment induced failures becomes much more necessary. The additional complexities

of the stress test equipment and failure analysis can add cost elements and is best applied when a more complex program is needed.

Step-Stress Testing Summary

The use of step-stress tests to provide rapid answers for a test program has been briefly discussed. There are other uses for this type of stress test. For example, it is quite easy to conduct an appropriate step-stress test sequence for successive lots, or at different time points, to determine the homogeneity of a product. Under any set of test conditions, which produce responses, it would be expected that the response for different populations would be the same (within measurement error) if the populations were homogeneous. This type of test is also often used by device manufacturers to assess process changes. These programs are often more detailed than the sample program which has been described since the derived information must be related to the particular processing step in which the change was initiated. Other uses for step-stress testing include:

- Inducing and identifying failure modes and determining the relations of stress and stress levels,
- Determining effective stress screens,
- Establishing thresholds and ultimate capabilities,
- Identifying the principal appropriate parameter measurements.

There are two major assumptions made in step-stress testing; the first being that the steps that preceeded the one in which failures occurred did not result in a cumulative degradation of the devices under test, and the second that the responses observed are the same as those that would be observed at a lower level of stress, if the stress were continued for a sufficient length of time. The second problem also occurs in accelerated life testing. The first assumption is generally true at the lower levels of stress, but may not hold as the stress level is made high, particularly if the maximum ratings of the device are exceeded. The second assumption is also usually true for low stress levels but the possibility of reaching a stress level which will exceed the activation energy of a new failure mechanism must be considered. The possible violation of the assumptions does not mean that the techniques are unusable, but only that the results must be carefully analyzed and that good engineering judgement must be applied.

A graphic display of the step-stress type of testing is shown in Figure 1, in which the curve shows the successively increasing levels of stress. The choice of the stress, or stresses, to include in the program for surface instability has already been indicated. The stresses which have been found effective for other failure mechanisms are indicated below. Again, tests involving humidity cycling with bias, or humidity life, are most applicable to non-metallic encapsulations.

For potential failure mechanisms associated with sealed junction integrity, the following accelerated activation stresses are applicable:

- High temperature storage with applied bias,
- Operating power,
- Humidity cycling with applied bias,
- Humidity life,
- Thermal shock,
- Temperature cycling.

The failure mechanisms revealed in long life reliability tests may be accelerated by high stress levels such as:

- High temperature storage,
- High temperature storage with applied bias,
- Operating power,
- Humidity life,
- Thermal shock,
- Temperature cycling.

The mechanical stability performance can be assessed by accelerated levels of tests such as:

- High temperature storage,
- Operating power,
- Thermal shock,
- Temperature cycling,
- Thermal fatigue (for power devices).

Lot Acceptance Programs

Lot acceptance programs are conducted on samples of the production population and the results are normally expressed as the number of failures in the sample, for each of the required groups of tests. If the number of rejects is less than the specified allowable number, then the lot is accepted. Most manufacturers conduct this type of test as a part of the quality control monitoring procedure. When a new device type is introduced into production, it is necessary to establish the test monitoring techniques and the limits to be specified for the device. This can be determined economically with the use of step-stress tests, for each of the areas of interest.

In this case, devices would be stressed at continuously increasing levels until a significant amount of response was produced. The level at which the responses occurred would be recorded and then a constant stress-in-time test could be run at a lower level. The latter test would remove the effects of any bias produced by the preceding stress levels, since the devices under test would only be stressed at one level. The point at which the failures were produced, particularly if they were catastrophic, would give the destruction threshold of the device for that particular stress. It would probably be necessary to conduct tests at more than one

constant stress-in-time level so that the degree of safety factor to be incorporated in the rating could be determined.

Complex Reliability Programs

There has been a body of knowledge developed as the result of the many reliability investigations that have been conducted in the past, particularly those programs that were concerned with the investigation of the physics of failure of semiconductor devices. These programs also were used to determine the types of stress tests that were most effective in revealing potential failure mechanisms. As a result of the improvement in semiconductors, the determination of failure rates has become more difficult. The conventional approach of conducting long term life tests, with many devices, has become less and less effective and economic. The alternative approach uses accelerated tests and develops models of the device response to stress, and then extrapolates the results to the use levels.

When one of the complex programs is being designed, there frequently is some doubt as to the proper stresses, or the proper parameters to monitor during the stress tests. Although a little more time will be required, the most effective approach is to conduct an exploratory series of tests first, and then conduct the comprehensive tests of the main program. This type of program will usually make use of step-stress and constant stress-in-time stresses, the Arrhenius and Weibull models, and will often require from 300 to 500 devices and from three months to over a year, depending on the depth of the study.

The step-stress test was described in the preceding paragraphs and was illustrated in Figure 1. The same kind of illustration is provided for the constant stress-in-time test in Figure 2. It can be seen that this is the conventional type of life test which consists of stressing devices at a fixed level for some period of time. Normally there are several readouts of the parameters during the test time, so that trends in the device response to the stress can be detected as early as possible. The results of these tests can be used to estimate failure rates directly, to compare the amount of response of devices with and without process changes, and as a stress screen for very high reliability devices. The assumption that is made with this type of testing, at high levels, is that the effects observed are the same as those that would be observed at lower stress levels if the test were extended in time. Unlike step-stress tests, the results here are free of any bias from the effects of previous stress tests.

Exploratory tests are particularly valuable for integrated circuits and new devices such as MOS arrays. In the case of integrated circuits, it is difficult to conduct accelerated tests with power or voltage since not all of the elements are available at the package terminals, and the maximum stress is limited by the weakest element in the chain. The most useful acceleration parameter that has been found to date is to raise the ambient temperature while conducting the stress tests. The exploratory series of tests can be used to find the most effective stress levels, and as an aid in determining the correlations between the parameter measurements and the device performance in the intended application.

Assume that a device is to be evaluated about which little is known, and that an estimate is to be made of the failure rate in normal operation. The exploratory tests will be step-stress tests of 72 hours duration per tread and will use approximately 20 devices per stress cell. A typical matrix for the tests would include:

- Temperature only stressing, to isolate temperature dependent effects from those observed for temperature plus bias,
- Operating life tests, at two bias levels to determine if there are any effects accelerated by the voltage level,
- Operating life tests at two power levels with the same bias voltages to determine the effects of current acceleration,
- Temperature plus reverse bias to investigate the possibility of inversion layer formation,
- Mechanical and environmental tests run for extended numbers of cycles.

The results from these tests would be analyzed to determine which stress tests provided the greatest response in terms of degradation failures. The failed devices would also be checked to make certain that the response was legitimate and was not a test equipment induced failure. This would involve the use of control lots, looking for patterns of responses and failure analysis. After this, the comprehensive stress tests could be selected and the experimental design completed for the main portion of the program.

The main portion of the program would generally consist of constant stress-in-time tests run at those levels selected from the exploratory tests, plus a replication of one or two of the step-stress tests to insure that the results obtained can be repeated. It is highly desirable to use devices from more than one production lot so that the possibility of lot-to-lot variations can be examined. The number of lots must be kept small however, or the number of devices on test will become quite large. The results of this program can then be used to estimate the performance and such functions as the failure rate by the use of response modeling techniques.

A program of this type was designed and conducted recently to provide reliability

information for epoxy encapsulated transistors[6,7]. A preliminary step-stress test plan, shown in Figure 3, used temperature only, temperature with two values of reverse bias and operating power with two applied voltages. The results of this test program were then used to design the constant stress-in-time test plan shown in Figure 4. It may be seen that it was possible to use single stress levels for the temperature only and temperature with reverse bias stresses to obtain the needed information. The operating life tests were conducted at two applied voltages for each of three power levels to provide a number of points to be used in the response modeling. A straight line can always be drawn through two points, but it is possible to be much more confident in the model if several points lie on, or very close to, the line.

Control Lots

In conducting any of these programs, a great amount of reliance is placed on the generated data. The use of measurement control lots adds very little to the cost of the program and increases the confidence in the results by a large amount. The majority of electrical readouts are made on automatic test systems, and the accuracy and repeatability requirements are pressing the equipment capabilities. The measurement control lot establishes a standard which will enable the detection of minor equipment variations. A reasonable number of units to choose is 10 representative devices with the parameter values being near the upper and lower limits of the specification requirements. These units should be read at the start and finish of each readout group or, in the case of long test times, every four hours.

One of the definite advantages of the measurement control lot was evident on a large scale program[2] during the monthly preventive maintenance checks. In recalibrating the entire test system, it was found that the summation of circuit variances was large enough to cause apparent shifts in parameters such as low level reverse currents, even though the entire system was still within the overall tolerance requirements. The control units were used in the recalibration of the system; fine tuning each circuit in order to have the overall system read as close as possible to previous readings. Alternatively, minor shifts in the control lot could often be correlated with minor shifts in the stress readings and the data could be adjusted. Many valuable test program hours were saved by being able to determine initially such things as operator or equipment malfunction setup errors, and out of tolerance conditions.

Response Modeling

There are several techniques used to make failure rate estimates, but one often used makes the assumption that the underlying distribution of life is of the exponential form. If this assumption is made, then it must also be assumed that the rate of failure is constant[5]. In the case of many semiconductor devices, the actual failure rates are decreasing in time; which results in a conservative estimate of the actual failure rate. The net result if that a safety factor has been added, and thus the user should find better results than were estimated.

When it is desired to check whether the failure rate is increasing, decreasing, or constant in time, the Weibull model plot provides a relatively simple tool. The model is also useful for other purposes since it provides an estimate of several characteristics in the failure time distribution. This model is discussed extensively in the literature and will only be described briefly here. A sample probability plot of failures-in-time represents an estimate of the cumulative distribution function, c.d.f., of the population. This function $F(t)$, is a non-decreasing function from 0 to 1, and for a given value of t, such as t_o, represents the probability of a device failing in t_o time units of life, or sooner. When the mathematical form of the cumulative distribution characteristic is known or assumed, special probability paper can be constructed for the model and will result in a straight line plot of $F(t)$. The linear Weibull probability plot shown in Figure 5 is an example of this. The Weibull c.d.f. is:

$$F(t) = 1 - \exp \frac{-(x-\gamma)^{\beta}}{\alpha}$$

$$\text{for } x \geq \gamma \geq 0,\ \alpha > 0,\ \beta > 0$$

$$= 0 \quad \text{for } x < \gamma \text{ where:}$$

γ is the location parameter, also referred to as the threshold or guarantee period,

α is the scale parameter,

β is the shape parameter and represents the slope of the probability plot.

The measure, or estimate, of β is such that if:

$\beta < 1$, the failure rate is decreasing with time on stress,

$\beta > 1$, the failure rate is increasing with time on stress,

$\beta = 1$, the failure rate is constant with time in stress; and the

Weibull failure-in-time distribution reduces to the exponential failure-in-time distribution.

The function is often expressed as the complement function, $1 - F(t_o)$, which represents the reliability function $R(t_o)$ and is the

information for epoxy encapsulated transistors[6,7]. A preliminary step-stress test plan, shown in Figure 3, used temperature only, temperature with two values of reverse bias and operating power with two applied voltages. The results of this test program were then used to design the constant stress-in-time test plan shown in Figure 4. It may be seen that it was possible to use single stress levels for the temperature only and temperature with reverse bias stresses to obtain the needed information. The operating life tests were conducted at two applied voltages for each of three power levels to provide a number of points to be used in the response modeling. A straight line can always be drawn through two points, but it is possible to be much more confident in the model if several points lie on, or very close to, the line.

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The function is often expressed as the complement function, $1 - F(t_o)$, which represents the reliability function $R(t_o)$ and is the

probability of the device surviving at least t_o time units of life. In general, it is possible to estimate the central tendency of the data, such as mean life, from the probability plot as well as to estimate the variability and other distribution characteristics.

The Weibull model has been successfully applied to component failure-in-time data at different fixed stresses. This failure-in-time analysis is essential for establishing burn-in levels and burn-in time, as well as providing information on accelerated test conditions, which can then be used to produce failures in reasonably short times.

Another useful model is the Arrhenius model, which was originally developed to be applied to the rates of chemical reactions. Since many of the surface failure mechanisms present in semiconductor devices are chemical in nature, such as the movement of impurity ions in the passivating oxides, the Arrhenius model has been successfully applied to life test data. This is quite often done in the form of plotting accelerated life test failure rates against the reciprocal of junction temperature to develop a failure rate versus stress level curve. The choice of these scales may be seen from an examination of the model equation. In general, the model may be described by the equation:

$\lambda = \exp^{(A + B/T)}$ where:

λ is the response parameter of interest such as the failure rate,

A and B are constants,

T is the absolute temperature in °K.

If the logarithm of λ is plotted against a linear reciprocal scale of T, then the constants A and B represent the intercept and the slope, respectively, of the resultant straight line plot. For this particular application, the slope, B, is related to the activation energy of the reaction which caused the failure. The development of a model in this form, in conjunction with device reject analysis, offers insight into the nature of the failure mechanisms and the rate of degradation, or the activation energy of the degradation process. When a dominant failure mechanism is detected and is accelerated with temperature according to the Arrhenius model, valid acceleration factors can be established over the region of testing and then be extrapolated to lower temperatures. An example of this is shown in Figure 6.

The curves shown in Figure 6 are typical of the forms that can be obtained for an Arrhenius model. The Double Failure Mechanism Curve can be observed when a second failure mechanism is activated above some stress level. In this case, an increase in the average failure rate would be observed for increasing stress. The slope of each portion can be related to the activation energy so that it is possible to determine not only when the mechanisms are activated, but at what level the devices can be operated to avoid triggering the second mechanism.

The failure rate, for each junction temperature, is lower for the left hand curve of the pair of Single Failure Mechanism Curves. If this type of plot had been obtained after a process change, it would indicate a definite improvement in the response to the stress which had been used. If the plot had been obtained for the evaluation of two competing products, the devices represented by the left hand curve of the pair would be more reliable.

There are other ways in which the pair of Single Failure Mechanism Curves could have been generated. For example, the junction temperatures shown in the model could have been obtained by conducting operating life tests at appropriate power levels to obtain the temperature rise. If the applied voltages for the stress tests were two different values (as in part of Figure 4), and the pair of curves were obtained, then a power acceleration of failures would be indicated. If it could be shown that the failure rate was independent of current level, then the voltage acceleration could be calculated. In the case of the illustrative curves, it would be possible to calculate directly the reduction in the estimated failure rate as a function of voltage derating.

Conclusions

The techniques described were not developed as abstractions or theories, but were derived through the experience gained in conducting many reliability evaluations. Several of these programs have been referenced in this paper. The techniques work, and become more effective as experience is gained in semiconductor devices and response patterns to stress. The principles have been applied to diodes[2,3] transistors[6,7], unijunction transistors [8] and bipolar integrated circuits[9] and the associated Test Element Groups, TEGs[3]. At the present time, programs using these techniques are in process to determine the benefits which may be obtained from the application of silicon nitride films to diodes and bipolar and MOS integrated circuits.

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Biography

Byron L. Bair received the B.E. degree from the Johns Hopkins University in 1955. Mr. Bair has represented the General Electric Company as the Chairman of the JEDEC, JS-8 Committee on Consumer Devices. He is also a representative on the GOSAM (G.E. Group on Semiconductor Applications and Measurements) Reliability Group. Mr. Bair has been engaged in reliability engineering for the past five years and is active in the design and technical administration of reliability programs and investigations. He has also been responsible for the analysis of reliability specifications to determine the compatibility of devices, test equipment and test procedures. Mr. Bair recommended changes in the specifications where desirable or necessary. The determination of reliability screens, screening limits, screening sequences, competitive evaluations, characteristic and reliability evaluations for grown diffused and planar passivated silicon diodes, transistors and integrated circuits have been included in his duties.

Biography

Albert Fox received the B.S. degree in Math and Physics from City College of New York in 1953. He did Post Graduate work in Electrical Engineering at Syracuse University from 1953-1960. He is a member of the American Statistical Association. Mr. Fox has been directly involved with many reliability engineering programs for the past eight years. These programs included all of the product types of the department and involved program design, analysis of data, reliability prediction, demonstration and establishment of degradation models relating to the physics of failure. He was the project statistician for the first generation Minuteman High Reliability Improvement Program; a complex design matrix for the silicon grown diffused transistor. He has conducted experimental designs, analysis and studies on other reliability contracts involving silicon discrete and monolithic integrated epitaxial passivated structures. He has applied statistical techniques for optimum decision making in semiconductor processing. Mr. Fox also has taught General Electric Company courses in Applied Mathematical Statistics and Design and Analysis of Experiments.

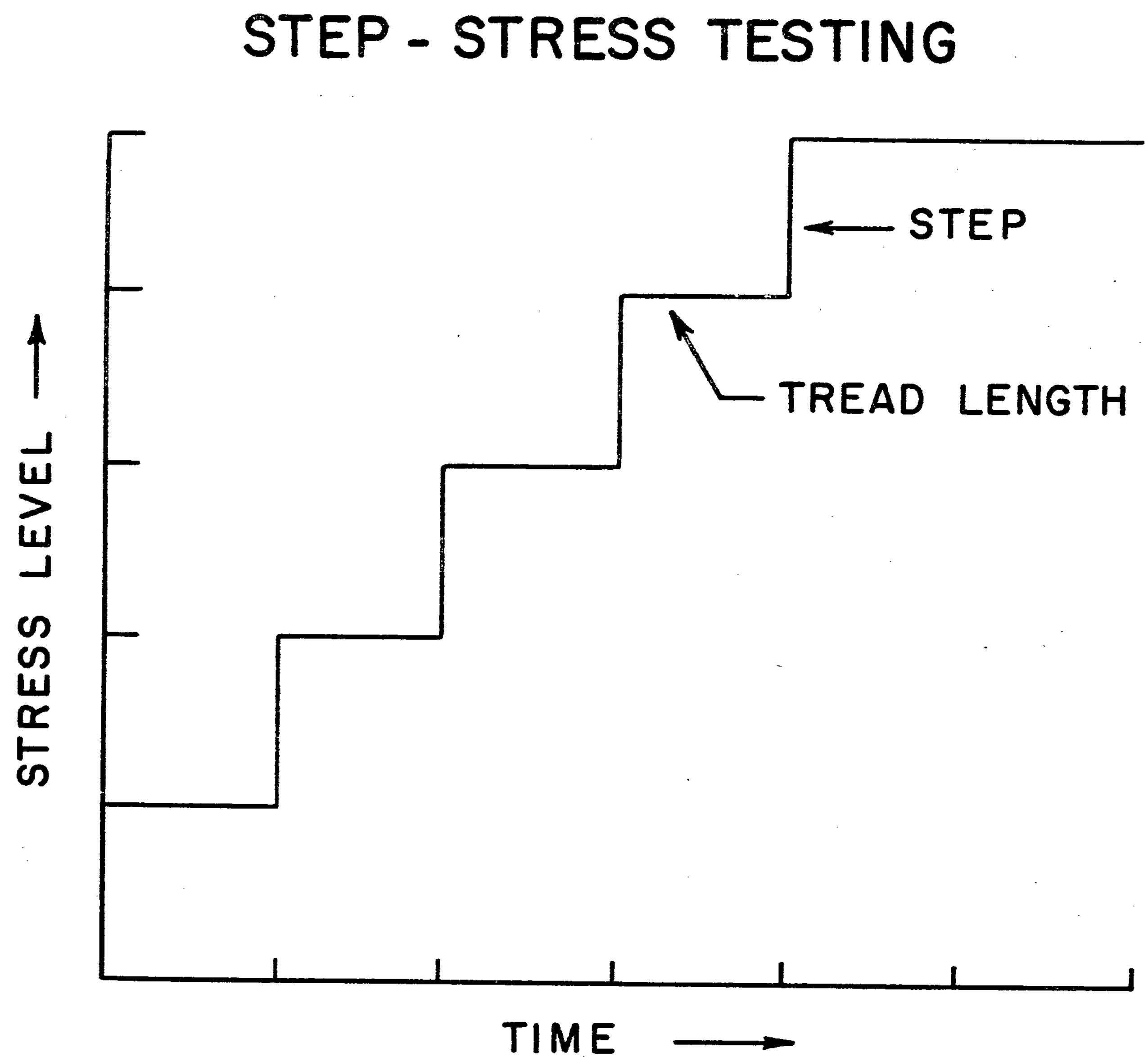


FIGURE I STEP - STRESS TESTING

CONSTANT STRESS-IN-TIME TESTING

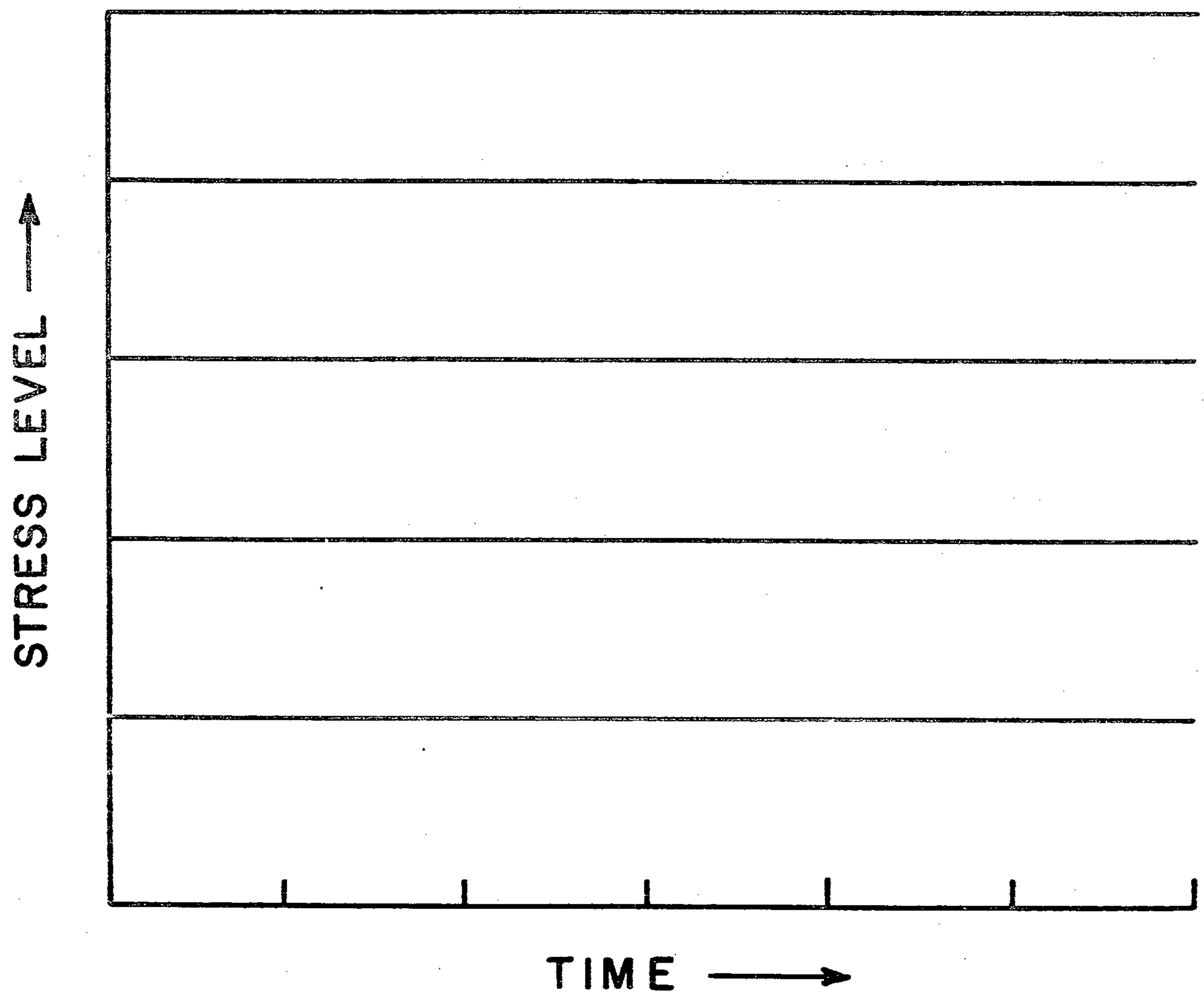


FIGURE 2 CONSTANT STRESS-IN-TIME TESTING

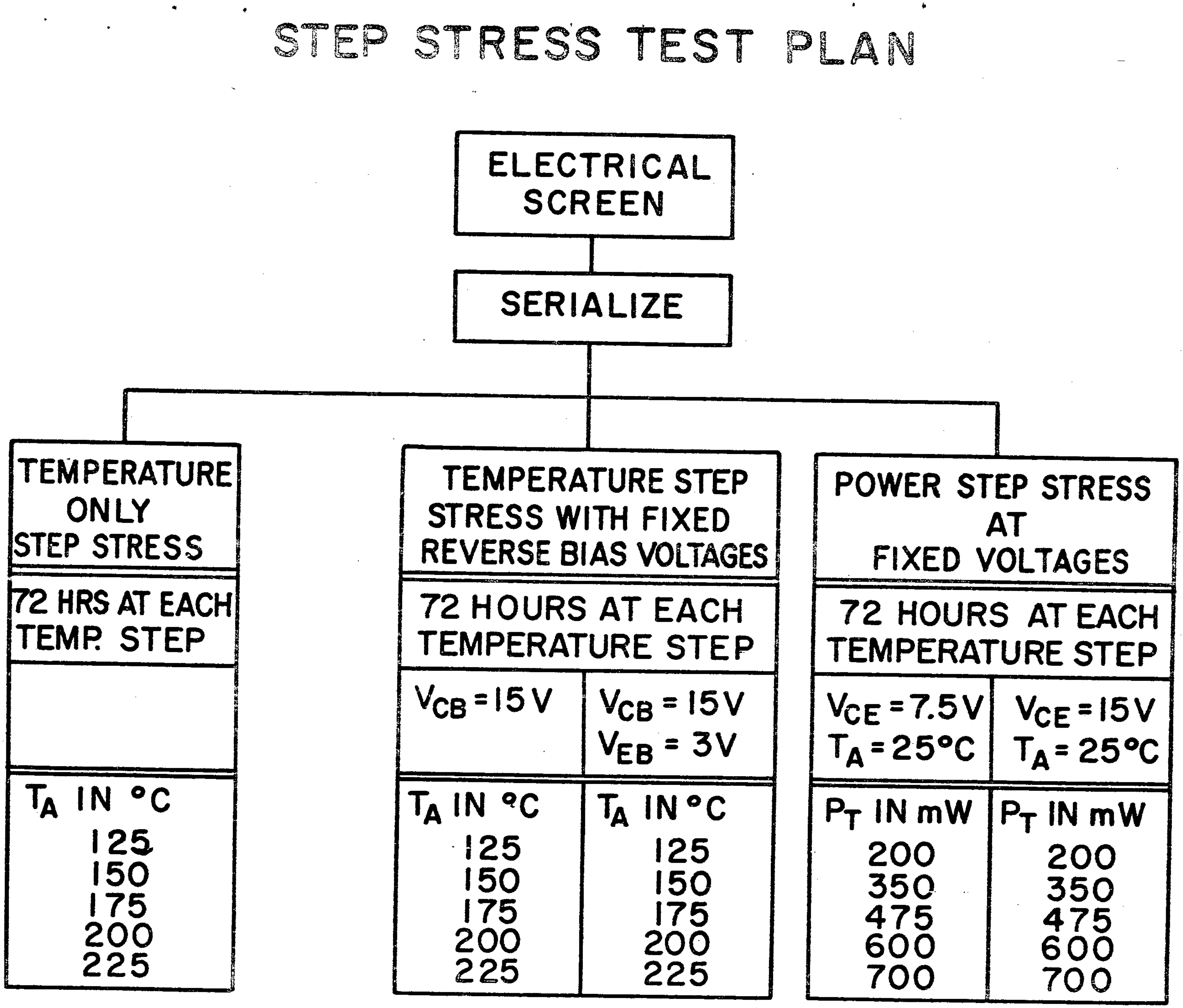


FIGURE 3 STEP STRESS TEST PLAN

CONSTANT STRESS - IN - TIME TEST PLAN

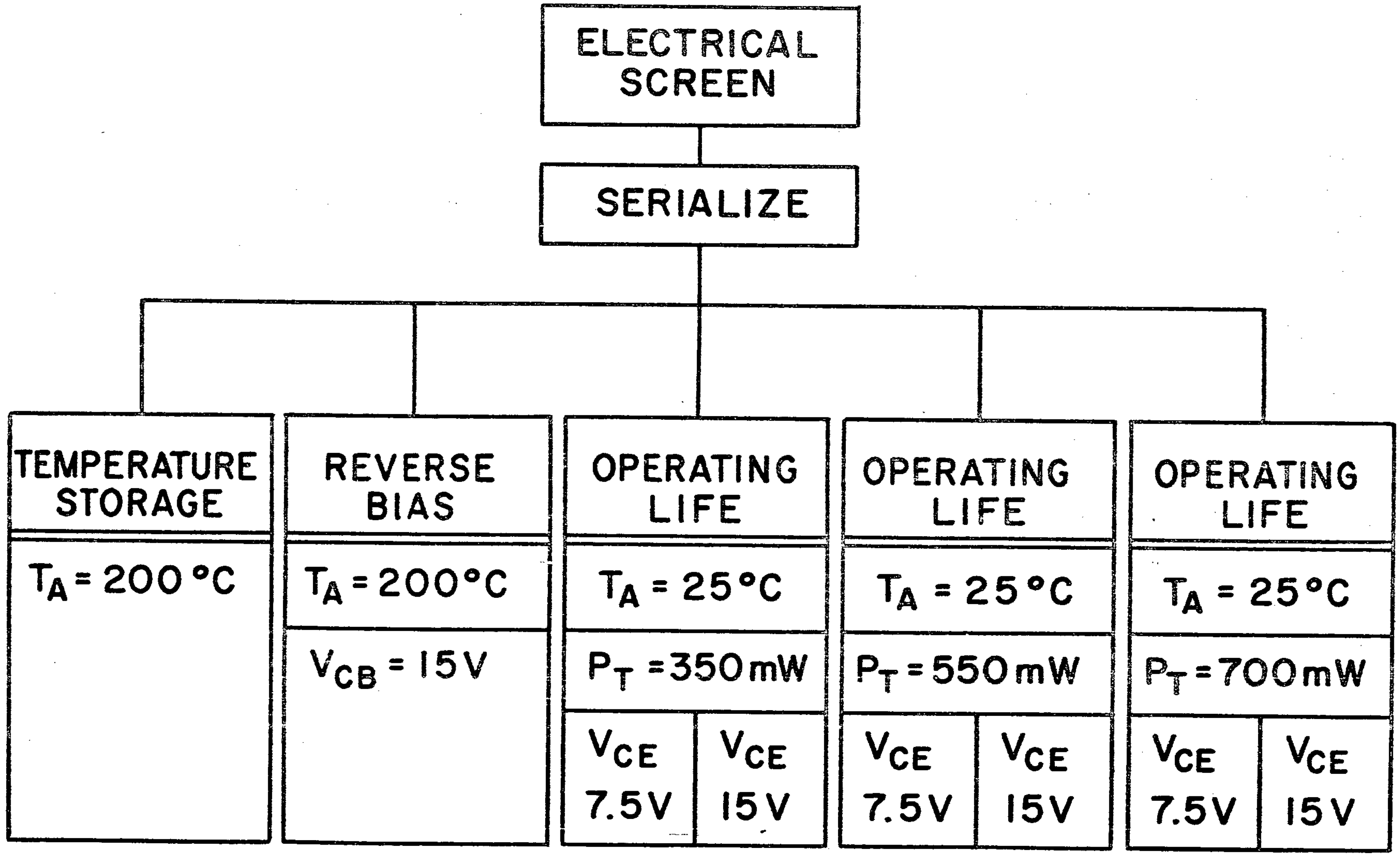


FIGURE 4 CONSTANT STRESS-IN-TIME TEST PLAN

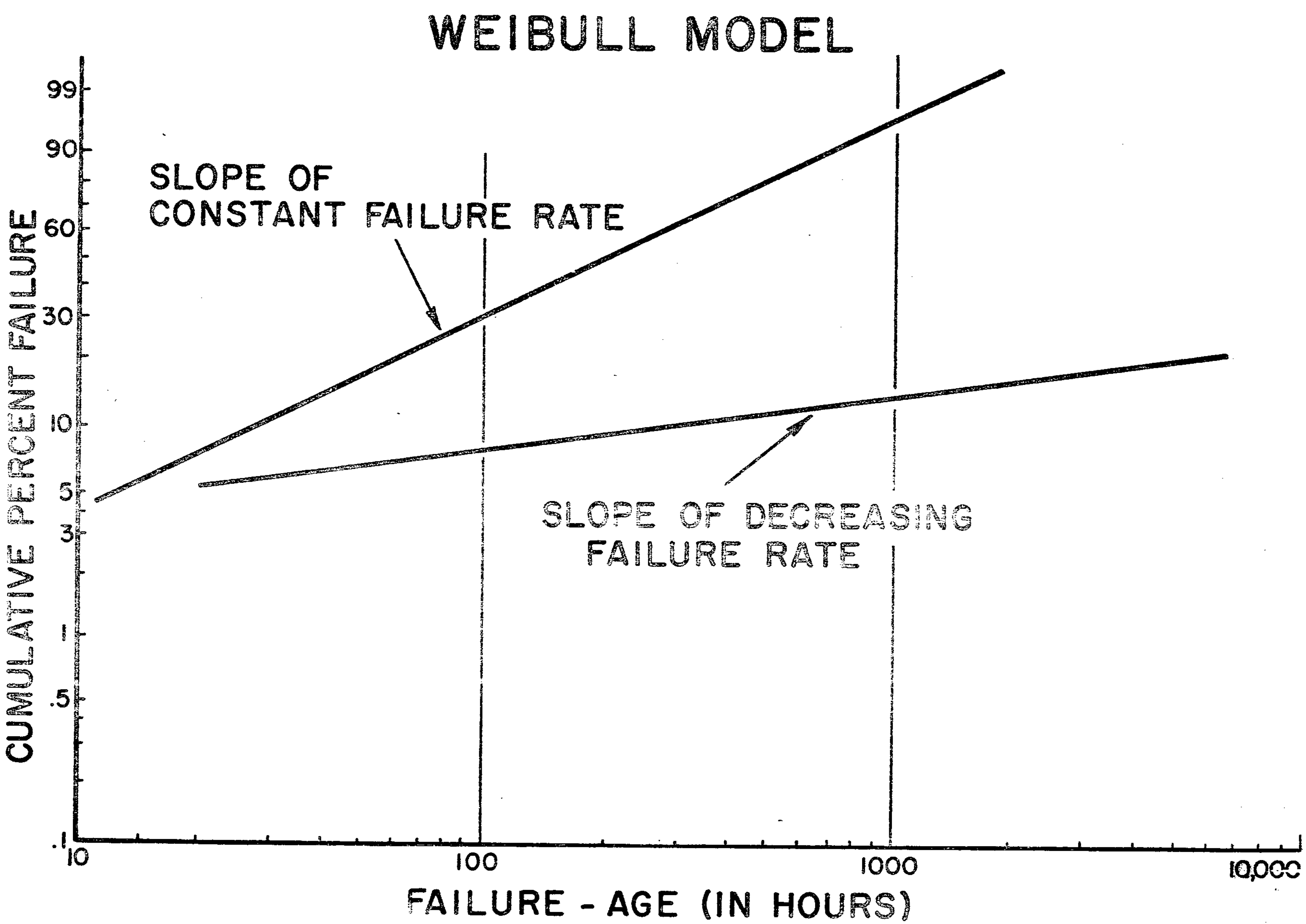


FIGURE 5 WEIBULL MODEL

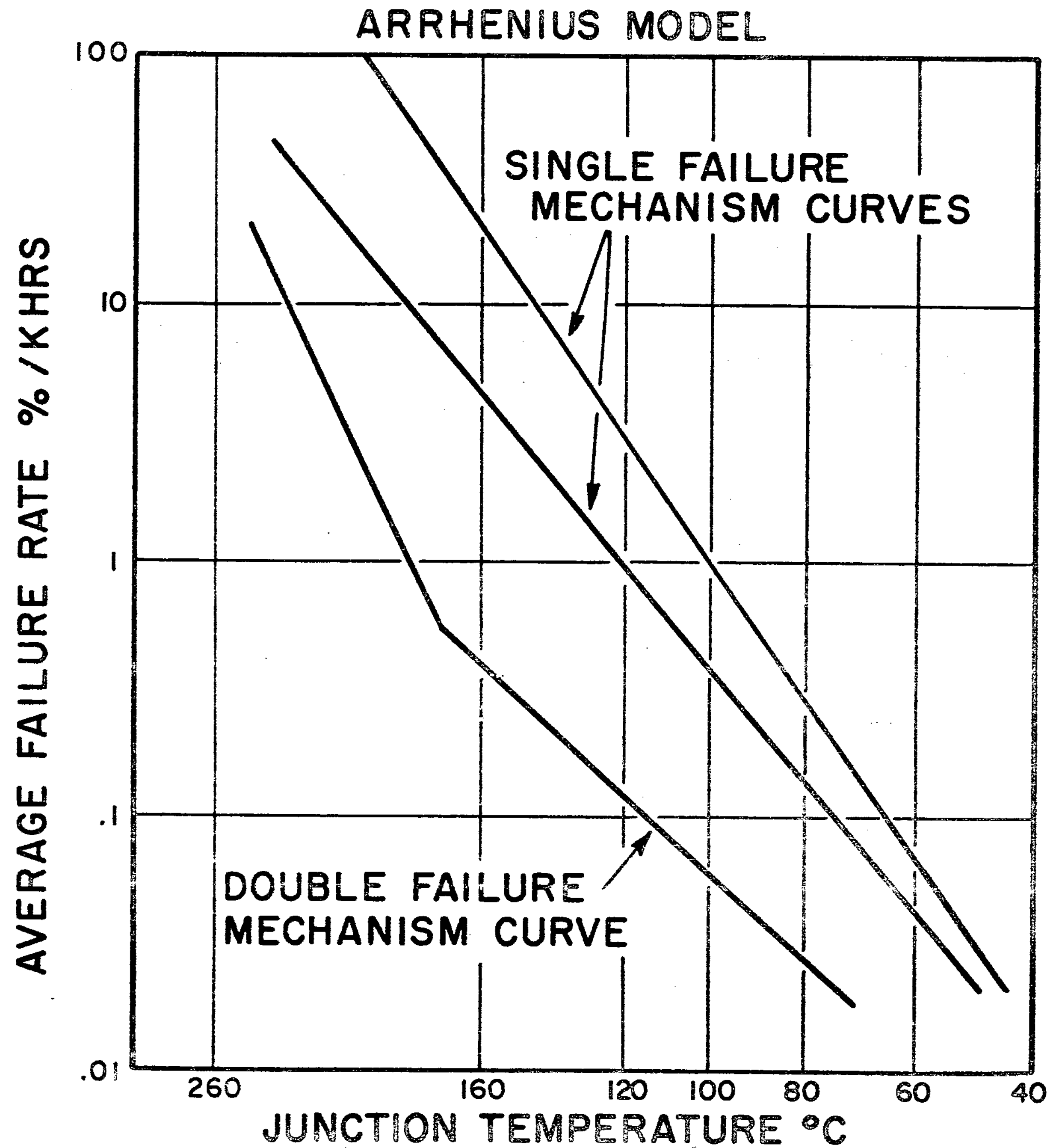


FIGURE 6 ARRHENIUS MODEL

QUALITY CONTROL IN A LARGE AIRLINE

Russ J. Thatcher

Director, Maintenance Quality

Air Canada

Montreal International Airport
Dorval, Quebec

Mr. Chairman, Ladies and Gentlemen.

I am very pleased to be given this opportunity to tell you about some of the philosophy, policies and people within Air Canada who help ensure the reliability levels that we have established and the related standards that the travelling public has a right to enjoy.

SLIDE 1

First, I want to clarify the meaning of the title of my talk - Quality Control in a Large Airline. When we talk about Quality Control, we are referring to the multitude of systems and people who all play their parts in the end product - from management to the technician, mechanic and clerk - both within and outside the Quality Division.

We emphasize the large airline because to a large degree it is the large airlines that pioneer new policies and procedures which other operators are able to use without any fear of economic or operational losses. Air Canada is a large airline; actually by the IATA standard of passenger miles flown, we are number seven in the world, excluding Aeroflot. The six ahead of us are all American operators. We average over 500 departures per day for a 1968 total of 200,000 flights.

SLIDES 2, 3, 4, 5

The size and extent of the airline operation has a bearing on the type of Quality Control that is applied. Our present route network involves a total of 59 stations, 44 of which we staff with our own maintenance personnel. We operate under very adverse climatic conditions with actual maintenance work being carried out on ramps at temperatures lower than 40° below zero and up to 100°F at our southern stations. We have to inspect airplanes out of doors with good daylight conditions and during inclement weather in the dark. All of these environmental conditions present their own special challanges which must be resolved.

SLIDE 6

(See App. 1 for print out)

In approaching our subject as a total maintenance system, we should first understand our basic organization as shown here on this slide. The major production divisions are Aircraft, Line Maintenance, Ground Equipment & Facilities and the Winnipeg Base. These groups are the major "doing" formations and as we all know, they play a very important role

in the final level of quality. The systems that we will be discussing later are woven through these production divisions.

The major staff groups are made up of Engineering, Planning, Administrative Services, Economics and Quality. We all report to the General Manager, Maintenance who reports to the Vice President - Operations.

In addition to all of the old axioms of the mechanic being the number one inspector and you can't inspect quality into a product, etc - we have an overriding general philosophy that starts at the top of our organization. Our General Manager expresses it as follows:

> "Quality is an attitude of management focused upon the development of individual skills, supported by technical data systems, equipment and facilities required to perform the individual maintenance tasks. Coupled with this philosophy, full time inspectors are employed in all instances where special inspection skills are required and where the nature of the work is related to fundemental airworthiness".

SLIDE 7

(See App. 1 for print out)

We can now refer to our next slide where we show the organization of the Quality Division.

The major inspection groups are Power Plant & Shops, Ground Equipment & Facilities and Aircraft. The Power Plant & Shops group, as the name implies, is responsible for the shop inspectors in these areas, the Stores Receiving Inspection function and approval of approximately eighty outside suppliers and repair agencies.

SLIDE 8

(See App. 1 for print out)

Ground Equipment is responsible for our Standards Room, station refueling inspections and check procedures on ground equipment. The Standards Room is responsible for 278 types of equipment with a total of 3700 items under their control. This flow chart, which you can follow in our notes, illustrates the routine handling of this test equipment. We are starting to subtract some of our Line Station equipment calibration checks at places like Vancouver and London, England to avoid shipping damage on some of the more delicate electronic test units.

This Quality section is also responsible for carrying out inspections of refueling facilities at each of our 56 stations at least once a year. This check includes taking a flow check at a fuel nozzle to measure the level of contamination in the fuel.

SLIDE 9,10,11,12

The Aircraft section is responsible for inspection of aircraft, non-destructive test (N.D.T.) and aircraft check schedules. We still rely on visual or eyeball inspection to a large extent as shown in this next slide of an inspector checking the interior of a DC8 outboard engine

pylon. We spend about $50,000.00 a year on X-ray film for inspections such as this shot from inside a DC8 cockpit out through the upper window frame. Another slide shows strip film being rolled up over a fuselage frame and in the next one we have the film rolls being inspected on the viewing screen.

SLIDE 13

The next slide is of Eddy Current equipment being used to inspect the back face of the rear compressor hub on a JT3D engine on a DC8.

SLIDE 14

Our next slide illustrates use of a 360° rod anode X-ray unit shooting the Conway front bearing housing with the film wrapped around the outer circumference.

SLIDE 15

This last N.D.T. illustration shows use of Ultrasonics in checking wheel hubs for cracks.

SLIDE 16

(See App. 1 for print out)

In all of our shop and hangar inspection areas, we have varied inspector/mechanic ratios. This next slide details the shops and aircraft functions with a total overall ratio of one (1) inspector for every twenty (20) mechanics.

SLIDE 17

(See App. 1 for print out)

As an aid in deciding when inspection is necessary on a particular job, we can refer to our next slide. Here we relate the numbers of natural opportunities to detect an error in a multi-process job as against a single process item where we may want to provide some additional inspection.

Our other functions are Quality Records and Quality Assurance. Quality Records are responsible for the total technical records systems for aircraft and ground equipment. We have always maintained a very comprehensive records system, since we have found that it pays for itself by enabling us to make better decisions on the many, major issues that develop in airline maintenance.

SLIDE 18

As an example of the extent to which we maintain this data, I have some figures on a Conway-powered DC8 airplane. On each DC8 we maintain time records on 1030 units and on 13,700 engine components for a total of 14,000 items. This information includes initials of the mechanic, and the inspector where applicable, date, total hours on the item, total number of landings, modifications embodied, stations where work was carried out and, in some cases, the time of day when the job was completed. Our combined manual and automated programs cover about 2 million individual items with approximately 90% of these in the power plant area.

This records system results in over 6,000,000 work items being signed for each year with existing fleets. The policy which dictates when work will be recorded and signed for is as follows:

> Work done consists of the act of either checking, changing, adjusting and repositioning

of aircraft parts, structures or systems and in addition the cleaning of or the removal of foreign material when associated with investigations or rectification.

This records system is primarily generated from a unit tagging system and the aircraft log book. Some aspects are still handled on a manual basis, but the majority of the basic engine data is automated.

SLIDE 19 & 20

The records section also is responsible for the processing of the tapes from our flight recorder. This involves the operation of a playback unit covering over 50 parameters that records 140 measurements every three seconds, from the moment the engines are started to the final stop at the ramp. We read the last take-off of a sample number of tapes for each aircraft every month as a check on parameter serviceability.

A logical next step after discussing this volume of records data is our Quality Assurance Programs which must monitor the total maintenance program to ensure compliance with our standards and the Company Approval System which is our delegrated authority from the Department of Transport (D.O.T.).

In order to tie our system into the Civil Aviation Authorities, we should explain our Company Approval System. The Department of Transport, Civil Aviation Division, has given us the authority to operate under an Approved Company System which is quite different from a private or small operator. Air Canada pioneered this new maintenance concept back in 1956. The majority of the world's airlines have now adopted this system or are in the process of doing so. Private or small operators must employ maintenance personnel licensed by the D.O.T. and they must obtain prior approval from the D.O.T. for any modification or repair carried out on their aircraft. In contrast, I will read the terms of our Approval:

Air Canada is approved as an organization to:

(a) Certify as airworthy the repair, modification and overhaul of those types of aircraft, engines, propellers, instruments, radio and electronic components, accessories and items of equipment which it is equipped for and competent to handle under the requirement of Paras. 1,2,3, and 4 below. (ICAO Annex 1, Fifth Edition, dated November 1962, Para. 4.2.4.).

(b) Issue a Maintenance Release for those types of aircraft which are maintained under its system of continuous maintenance and, in addition, to certify individual items of maintenance, servicing and associated work done on such other aircraft which it is equipped for and competent to handle under the requirement of Paras. 1,2,3, and 4 below. (ICAO Annex 1, Fifth Edition, dated November 1962, Para. 4.1.3).

The approval will remain valid until further notice provided that:

1. All necessary facilities, tooling and equipment are available for the proper accomplishment of the work involved.

2. All materials, workmanship and procedures are in accordance with standards acceptable to the Department.

3. The system of inspection is in accordance with standards acceptable to the Department, and further, that all inspection is by, or under the supervision of, personnel whose names and qualifications are filed with, and approved by the Department.

4. The names and qualifications of all personnel authorized to sign a Maintenance Release are filed with the Department, and further, that the system of establishing and maintaining the competency of such personnel meets a standard acceptable to the Department.

Our General Supervisor, Quality Assurance Programs monitors our total Quality programs and is responsible for the co-ordination of the Quality Audits which are carried out in each area. In addition, he maintains our Maintenance Quality Manual.

SLIDE 21

(See App. 1 for print out)

One of the new trends in the airline inspection area is the development of Audit programs. We, in Air Canada, have been carrying out routine Quality Audits for approximately 5 years. The major elements of Quality that are involved in our program are shown on this slide. Initially, we did not include skills since this was considered to be a very opinionated area which could present some problems in the acceptance by production. About a year ago we received a request from Production to include this element since they were quite pleased with our Audit reports and felt that our Inspectors were also capable of assessing this factor.

SLIDE 22

(See App. 1 for print out)

This slide lists the various areas that are covered by this Audit program which, at present, includes all significant regulatory and technical areas.

SLIDE 23

(See App. 1 for print out)

This slide is a sample of the actual inspection sheet that is used by the inspector, and in fact, is a list of questions that must be answered when carrying out the audit. The inspector's report goes directly to the Foreman or Supervisor of the area concerned with a routine follow-up of action after a two month period.

These audits are carried out by either Management or Union Contract personnel depending upon the area involved.

Although some of the Inspectors have some difficulty in writing an audit report, the change from the conventional inspection job to this new program has been well accepted by this group.

SLIDE 24

As mentioned earlier our Production supervision and the mechanic on the bench have also been quite pleased with our audit program. Needless to say we in Quality are convinced that we are doing a better job since we are working on the basic causes of poor quality in such areas as, instructions, manuals, equipment and tooling.

We would like to outline our general philosophy with respect to reliability which is an area receiving a great deal of attention in the airline industry these days.

Major changes in Maintenance philosophy have been evolved around the improved design characteristics inherent in modern aircraft, coupled with the scrapping of the classical "bathtub" curve as the major guidepost to correct maintenance programs.

In the past normal Quality or Inspection approach to a maintenance requirement was - the more inspection and maintenance you do, the higher the quality level. We now have a better understanding of life cycles and failure patterns. The current policy governing application of maintenance is that routine check work will only be called up when we can prove that our actions will detect and correct a deteriorating or sub-standard condition. Whereas in the past, we believed that the majority of the failures could be predicted, we now are convinced that the opposite is true.

<u>SLIDE 25</u>

(See App. 1 for print out)

In the past, we assumed that the "bathtub" curve with its infant mortality, random rate and wear out periods, applied to the majority of our problems. We now know that this is, in most cases, not a fact. We still have infant mortality although improved shop and pre-flight testing has reduced this problem. We find that the wear out characteristics as related to time since repair or overhaul only apply to a small number of units. In addition, the prediction of the wear out period is more difficult and we have to rely on the manufacturers' test programs or on our own or other airlines' actual experience. In effect, the great majority of our failures occur at random and our airplanes are designed to accept this fact.

This random failure pattern is, to a large extent, due to the multitude of different repair, build and modification standards that exist in a single family of units operating under a very wide range of operating conditions.

<u>SLIDE 26 & 27</u>

(See App. 1 for print out)

Our major change from fixed time overhauls on units to our random failure, on condition approach, was made in the fall of 1963. This slide illustrates the effect of this change in our DC8 fleet. We can see the drop in scheduled removals in 1963 and the corresponding reduction in unscheduled removals or failures in 1964. We attribute this improvement to less exposure to infant mortality. This chart on the DC9 unit removal program illustrates the further departure from fixed time overhauls.

We monitored the transition from fixed time overhauls to "on condition" handling with a very extensive sampling program. This involved complete teardown inspection of certain high time failures and selected high time scheduled removals in order to detect any signs of wear out conditions. This sampling program is still maintained on a smaller number of the more critical high cost items.

Since our personnel are a very important element in our control of quality, we maintain a Personnel Error Investigation system. Of the 6,000,000 work items we referred to earlier, we monitor personnel

errors that cause a Maintenance Delay, an Incident or a Power Plant Shutdown. Our 1968 experience on personnel errors was a rate of approximately .98%.

SLIDES 28,29,30,31,32

(See App. 1 for print outs)

On a monthly basis, we produce technical performance summaries which illustrate the results of all the combined efforts in the Maintenance Department. This summary covers such items as Maintenance Delays, Shutdowns, Unscheduled Unit Removals, Pilots Comments and Power Plant Removals, as shown on these charts.

SLIDES 33 & 34

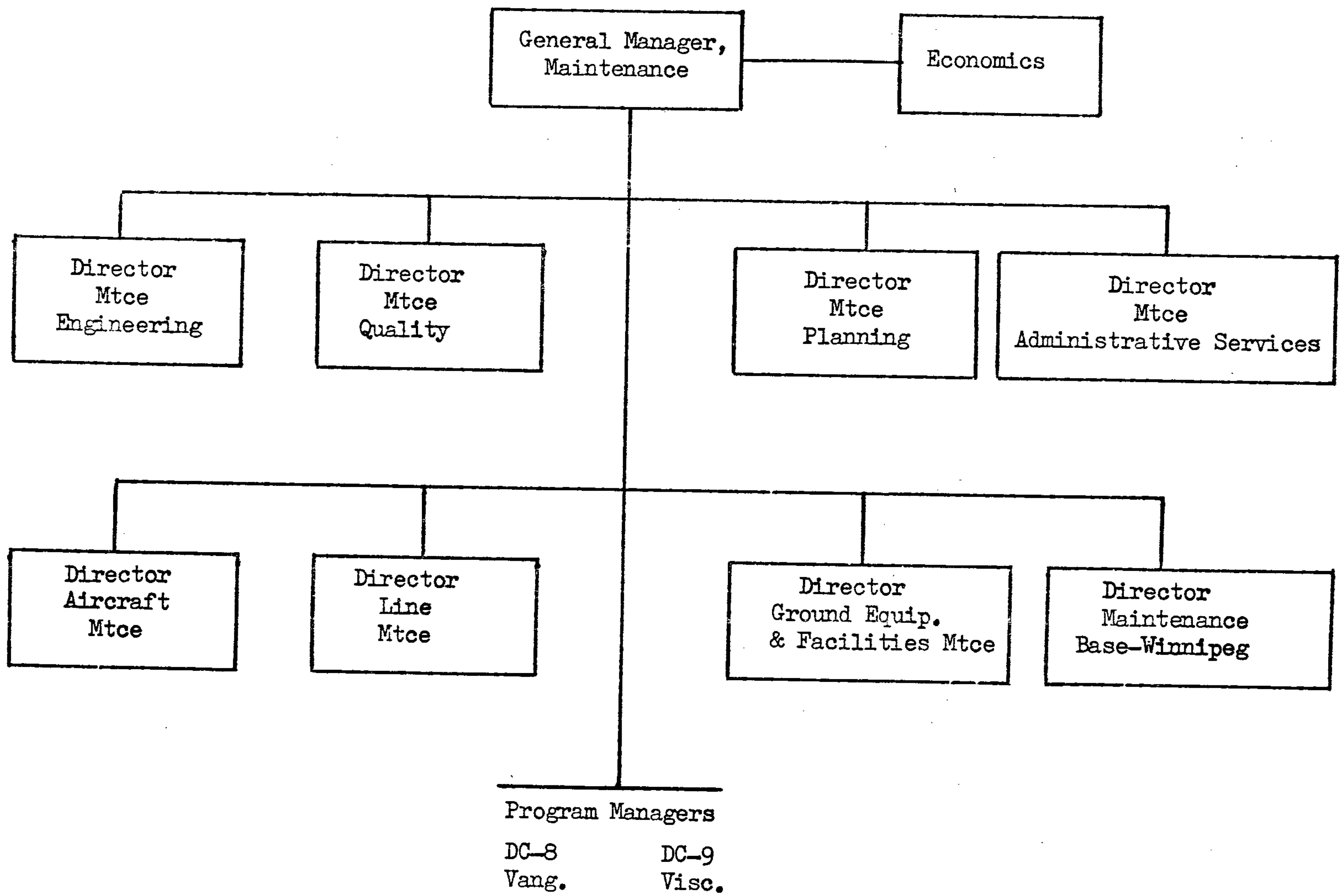
The final objective is a serviceable, clean and comfortable aircraft on the ramp to serve the travelling public. This goal can only be achieved by approaching our objectives with a total departmental program, guided by the Quality Division, to ensure adequate participation by every member of the team.

APPENDIX I

PRINT OUT OF SLIDES

SLIDE NO. 6	–	MAINTENANCE ORGANIZATION
SLIDE NO. 7	–	QUALITY ORGANIZATION
SLIDE NO. 8	–	STANDARDS SYSTEM FLOW CHART
SLIDE NO.16	–	INSPECTION/MECHANIC RATIOS
SLIDE NO.17	–	DEGREE OF INSPECTION
SLIDE NO.21	–	QUALITY ASSURANCE STRUCTURE
SLIDE NO.22	–	QUALITY ASSURANCE PROGRAMS
SLIDE NO.23	–	QUALITY AUDIT INSTRUCTIONS
SLIDE NO.25	–	FAILURE PATTERN
SLIDE NO.26	–	DC8 UNIT TREND CHART
SLIDE NO.27	–	DC9 UNIT TREND CHART
SLIDE NO.28	–	TECHNICAL PERFORMANCE – AIRCRAFT – FLIGHT DELAYS
SLIDE NO.29	–	" " " – IN FLIGHT SHUTDOWNS
SLIDE NO.30	–	" " " – UNSCHEDULED UNIT REMOVALS
SLIDE NO.31	–	" " " – PILOTS COMMENTS
SLIDE NO.32	–	" " " – POWER PLANT REMOVAL DATA

MAINTENANCE ORGANIZATION



SLIDE 6

Organization

1 Organization Charts

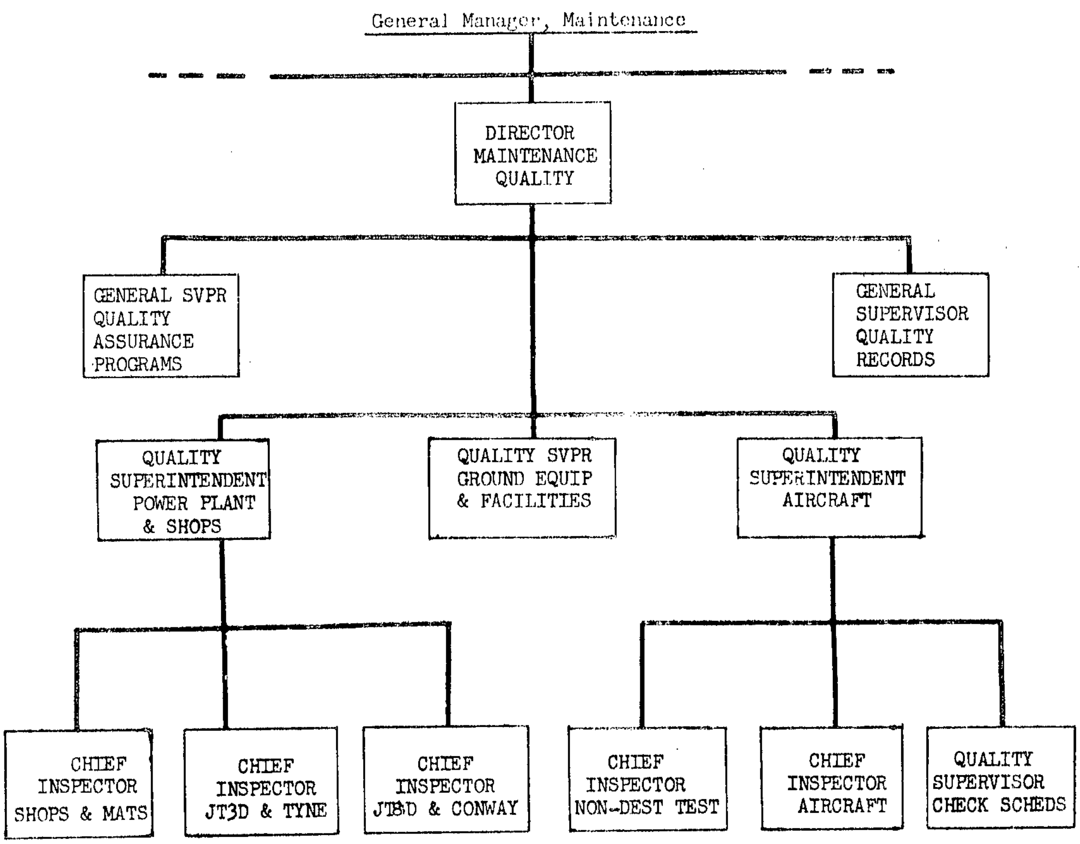
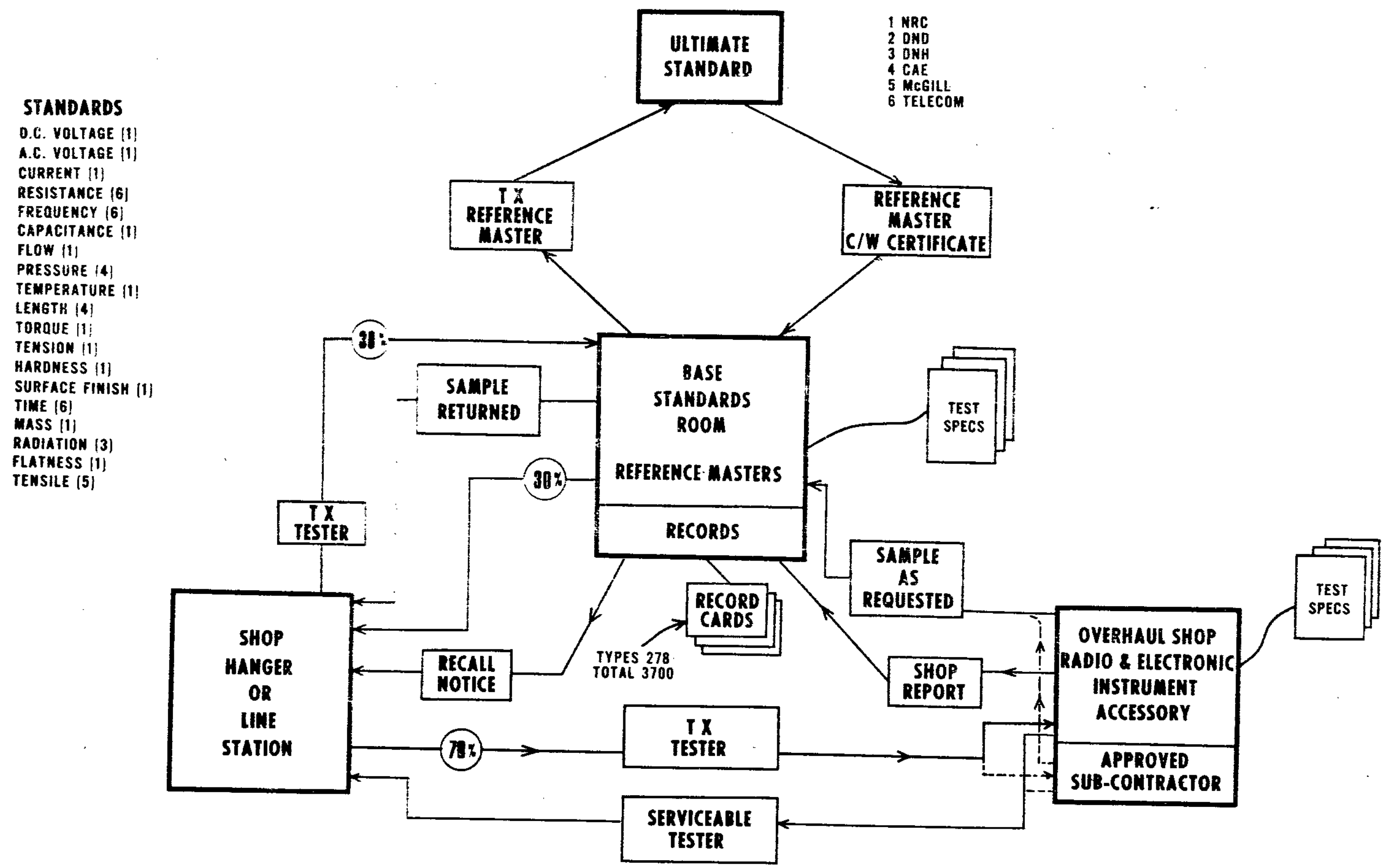


FIGURE 1 - ORGANIZATION CHART - QUALITY DIVISION - DORVAL

MAINTENANCE DEPARTMENT STANDARDS SYSTEM FLOW CHART



AIR CANADA

INSPECTOR/MECHANIC RATIOS

DORVAL – SEPTEMBER 1968

FORMATION	INSPECTORS	MECHANICS	RATIO
Aircraft Overhaul & Opn Checks	46*	510	1/11.0
Power Plant Shop	23*	347	1/15.0
Sheet Metal Shop	2*	135	1/67.5
Finishing Shop	1*	78	1/78.0
Wheel & Brake Shop	1*	25	1/25.0
Machine Shop	2*	114	1/57.0
Welding Shop	1*	28	1/28.0
Accessory Shops (4)	3*	205	1/68.5
Instrument Shop	1*	94	1/94.0
Process Shop	-**	19	0/19.0
Electronic Shop	-**	89	0/89.0
Paint Shop	-	42	0/42.0
Maintenance	4	311	1/77.7
N.D.T.	12	-	12/0.0
Receiving Inspection	7*	-	7/0.0
Total	103	1997	1/19.3

Remarks: 1. *Denotes Approved Inspection coverage.

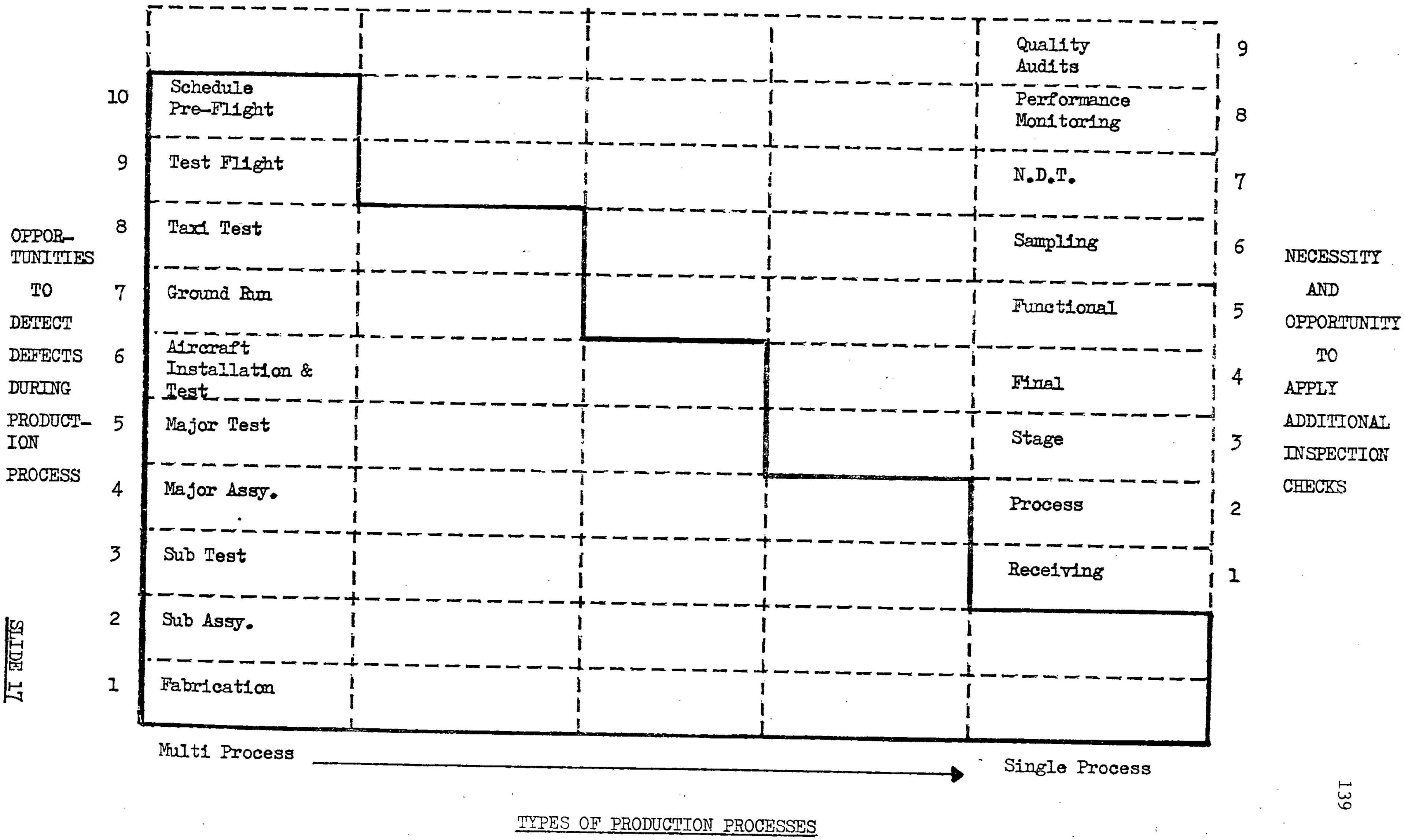
2. **Denotes Approved Inspection coverage by production.

3. Number of Mechanics incl. Lead and Certificated Mechanics but excludes Crew Chiefs.

4. The Maintenance Formation covers minor maintenance and Dorval Ramp personnel.

DEGREE OF INSPECTION

CHART



SLIDE 17

QUALITY ASSURANCE STRUCTURE

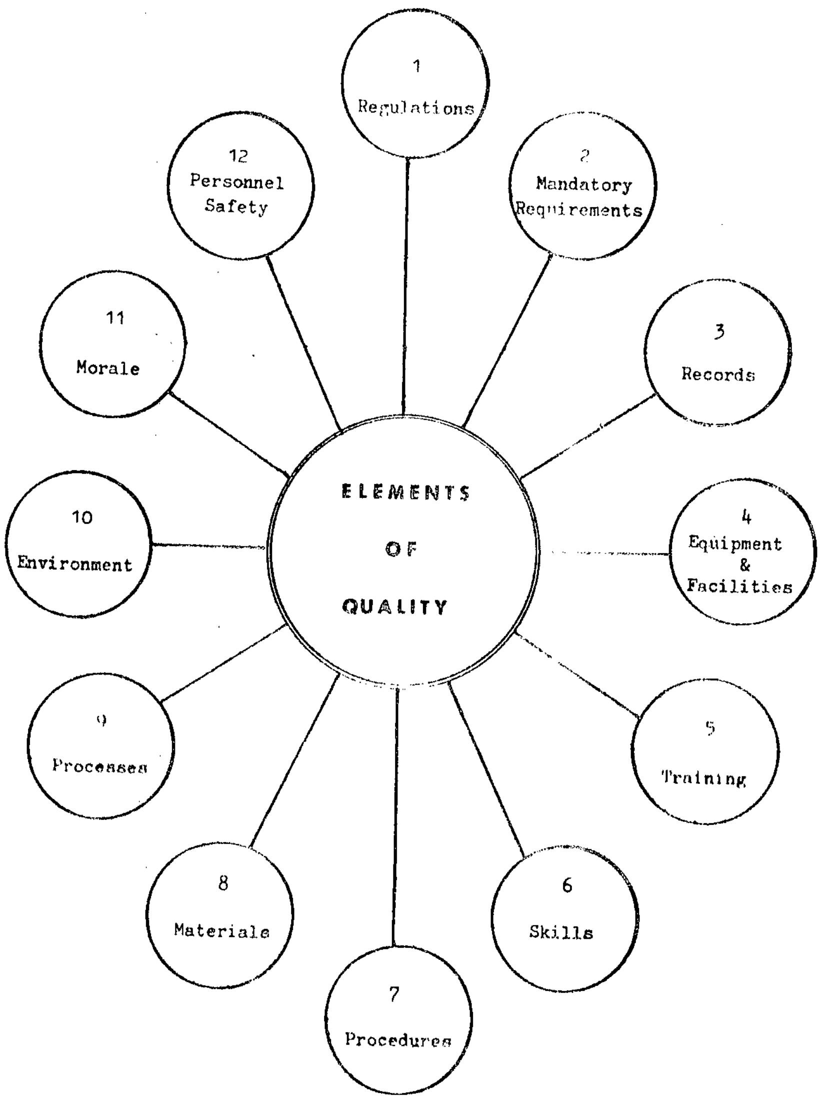


FIGURE 1 -- QUALITY ASSURANCE STRUCTURE

SLIDE 21

862 MAINTENANCE QUALITY

CHAP 16
PAGE 8
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Quality Assurance Programs

3 Arrangement of Program (cont.)

.12 List of Audit Instructions:

1. Maintenance Engineering
   - 1-1 Airworthiness Directives
   - 1-2 Maintenance Engineering Orders

2. Line Maintenance
   - 2-1 Line Stations
   - 2-2 Airline Pooling (not yet issued)
   - 2-3 Aircraft Maintenance/Line Maintenance (See 3-1)

3. Aircraft Maintenance
   - 3-1 Aircraft Maintenance/Line Maintenance (See 2-3)
   - 3-2 Inspection & Maintenance Programs
   - 3-3 Non-destructive Test Center
   - 3-4 Aircraft Log Book

4. Power Plant Maintenance & Shops
   - 4-1 Power Plant Shop - General
   - 4-2 Unit & Aircraft Support Shops
   - 4-3 Welding Shop
   - 4-4 Machine Tool Section - Machine Shop
   - 4-5 Stores Warehouse
   - 4-6 Stores-Receiving Section
   - 4-7 Suppliers & Sub-Contractors

5. Quality Records
   - 5-1 Quality Records, Aircraft - Kardex
   - 5-2 Quality Records, Aircraft - Flight Times
   - 5-3 Quality Records, Aircraft - Recall Control

6. Ground Equipment & Facilities
   - 6-1 Base Standards Room
   - 6-2 Aircraft Refuelling Facilities

Quality Assurance Programs

12-6

MAINTENANCE DEPARTMENT

QUALITY AUDIT INSTRUCTION

AIRCRAFT MAINTENANCE/LINE MAINTENANCE

Item or Function: ______________________ Audit Reference: 2-3 3-1

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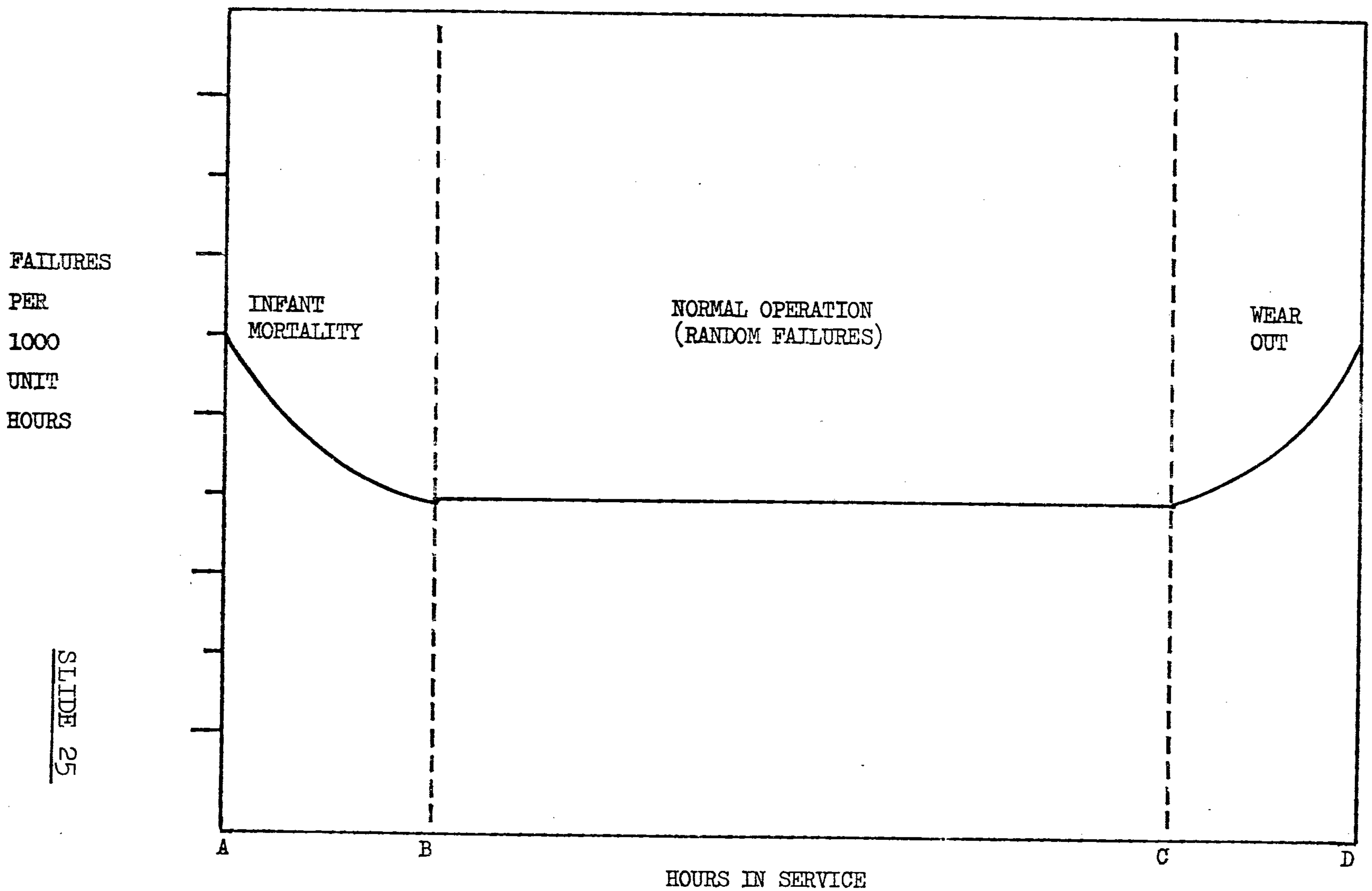
1. Are the Maintenance Manual instructions up-to-date, adequate, in good condition and readily available?
2. Are the check form(s) or job ticket(s) up-to-date and do they explain the job adequately on the ticket or in the applicable Maintenance Manual write-up?
3. Are the necessary torque values, fits and clearances specified and are they being adhered to?
4. Are the test procedures clearly defined, adequate and being adhered to?
5. Is the work performed to an acceptable standard of workmanship in accordance with good quality practices?
6. Is the work environment (i.e. lighting, cleanliness, etc.) compatible with good workmanship?
7. Are adequate tools, checking fixtures, test equipment and work stands available and used? Are they being regularly checked and maintained in good condition?
8. Are suitable blanks, caps and protective devices available and used?
9. Are correct locking devices fitted and adequately installed?
10. Are all deviations from established acceptance standards being covered by correctly approved Production Permits?
11. Are repairs covered by approved repair schemes?
12. Is correct lubricant (oil or grease) used? Is it clean and correctly stored?
13. Are correct parts available, correctly identified and properly stored?
14. Are all tags correctly completed?
15. Are check forms or job tickets correctly completed?
16. Are Log Book entries correctly completed?
17. Check that pilots' comments and snag deferments are in accordance with established Maintenance Manual procedures and Company policy.

FIGURE 6 - AIRCRAFT MAINTENANCE/LINE MAINTENANCE

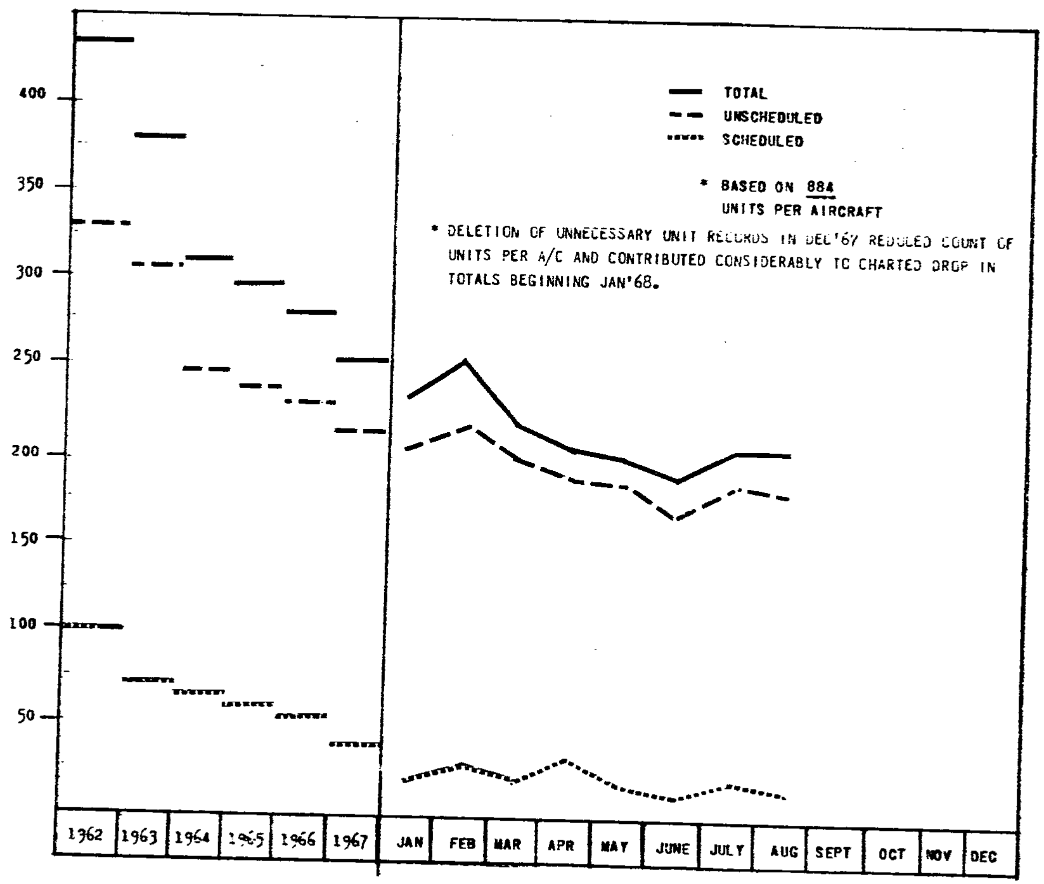
FAILURE PATTERN



SLIDE 25

MAINTENANCE DEPARTMENT

UNIT REMOVALS PER 1000 A/C HOURS - DC-8 - ALL SERIES

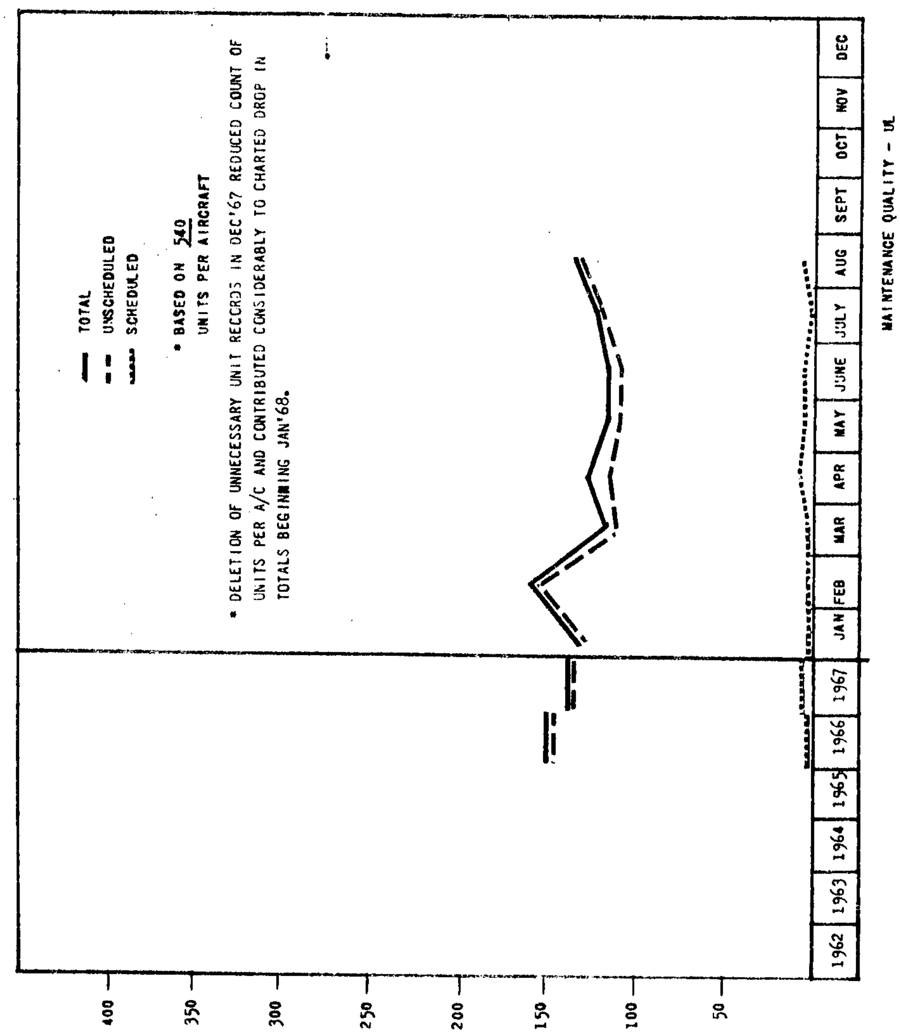


MAINTENANCE QUALITY - UL

SLIDE 26

MAINTENANCE DEPARTMENT

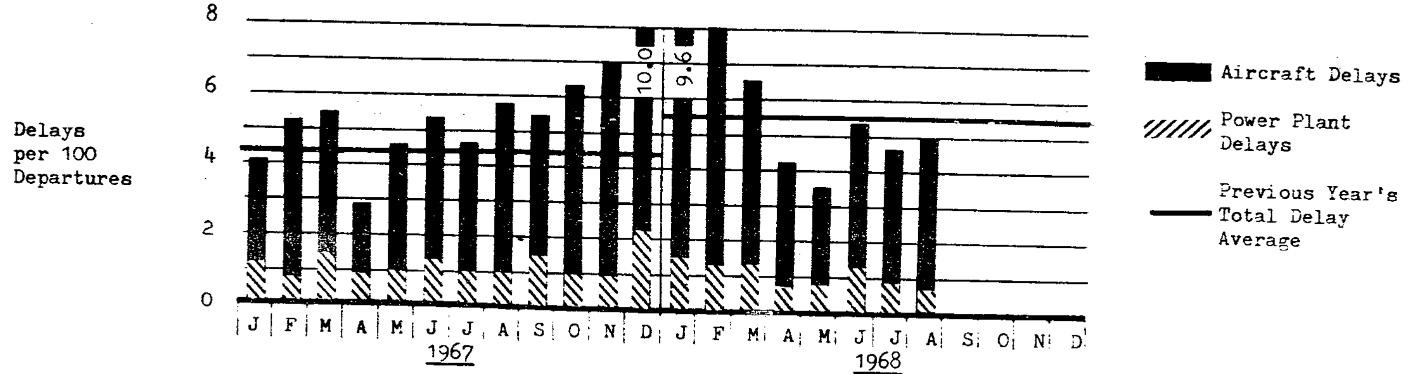
UNIT REMOVALS PER 1000 A/C HOURS - DC-9 & DC-9-32



SLIDE 27

TECHNICAL PERFORMANCE - AIRCRAFT

Flight Delays - DC-8 (All Series)



Delays/100 Departures 5.0 Flight Delays 129 Total Duration 98:23 Revenue Departures 2586

MAJOR ITEMS AND TRENDS

System No.	Description	Qty.	% of Total Indiv.	% of Total Cumul.	1-5	6-30	Delay Duration in Minutes 31-60	61-120	121-240	241 & Over
34	Navigation	16	12.3	12.3	4	8	3	-	-	1
25	Equipment/Furnishings	14	10.8	23.1	3	8	3	-	-	-
32	Landing Gear	13	10.0	33.1	1	9	1	-	-	2
24	Electrical Power	10	7.7	40.8	1	3	3	2	1	-
52	Doors	8	6.1	46.9	3	3	1	1	-	-
21	Air Conditioning	7	5.4	52.3	2	2	2	1	-	-
--	Remainder of Systems	62	47.7	100.0	13	24	10	6	6	3

NOTE: The totals in this list will not necessarily agree with the total delays above due to delays with split causes.

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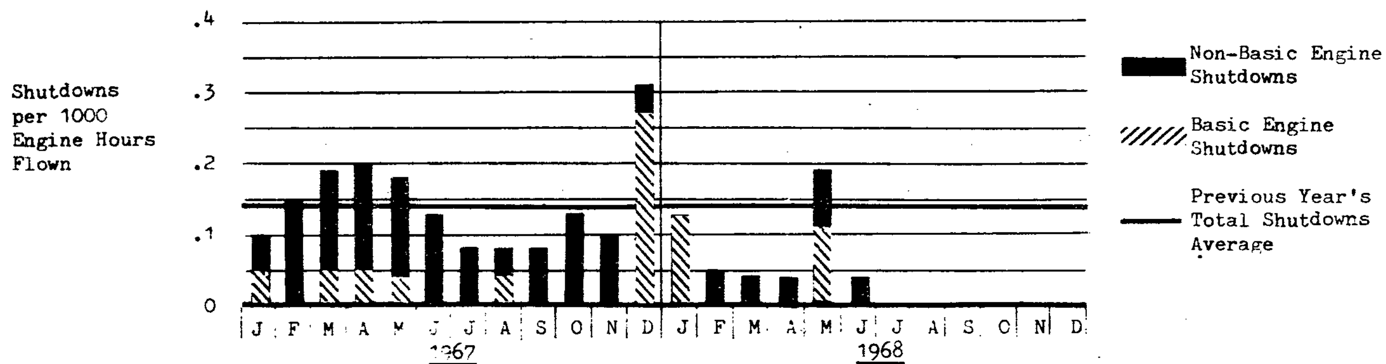
TECHNICAL PERFORMANCE - AIRCRAFT

In-Flight Shutdowns - DC-8 (All Series)



NO. PER MONTH	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
DC-8/40	2	2	4	4	3	2	2	1	2	3	1	7	2	0	1	0	5	1	0	0
DC-8/50/61	0	1	0	0	1	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0

MAJOR ITEMS AND TRENDS

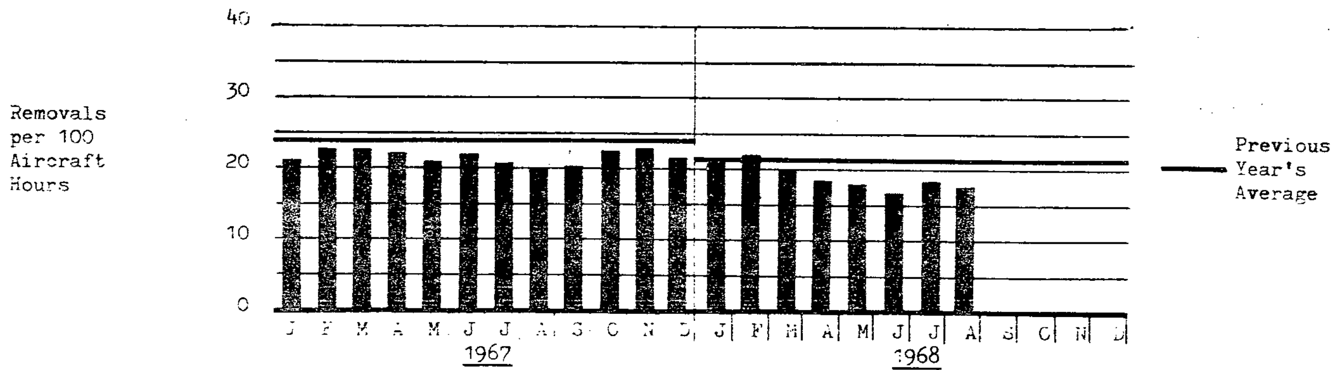
System No.	Description	Qty.	% of Total Individual	% of Total Cumulative

NIL IN-FLIGHT SHUTDOWNS

Sect. 2.1
Page 4

TECHNICAL PERFORMANCE - AIRCRAFT

Unscheduled Unit Removals - DC-8 (All Series)

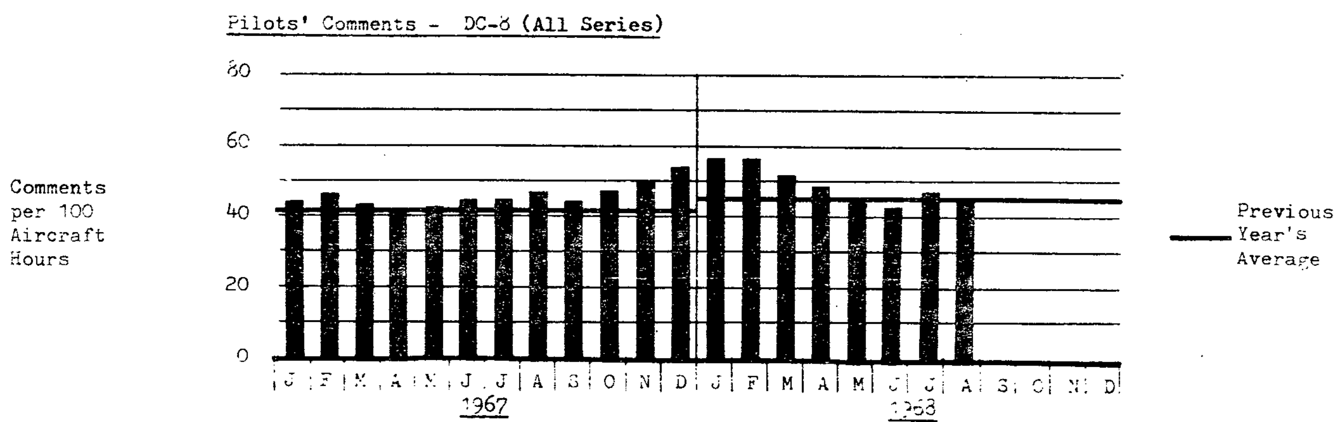


Total Removals 1430

MAJOR ITEMS AND TRENDS

System No.	Description	Qty.	% of Total Individual	% of Total Cumulative
34	Navigation	540	37.8	37.8
23	Communications	174	12.2	50.0
21	Air Conditioning	106	7.4	57.4
25	Equipment/Furnishings	83	5.8	63.2
77	Engine Indicating	80	5.6	68.8
28	Fuel	64	4.5	73.3
--	Remainder of Systems	383	26.7	100.0

TECHNICAL PERFORMANCE - AIRCRAFT



Total Comments 3555

MAJOR ITEMS AND TRENDS

System No.	Description	Qty.	% of Total Individual	% of Total Cumulative	Flights Per Comment
34	Navigation - Radar (127) - Doppler (191)	778	21.9	21.9	3.4
25	Equipment/Furnishings	696	19.6	41.5	3.8
23	Communications	278	7.8	49.3	9.4
21	Air Conditioning	221	6.2	55.5	11.8
28	Fuel	192	5.4	60.9	13.6
38	Water/Waste	140	3.9	64.8	18.7
--	Remainder of Systems	1250	35.2	100.0	2.1

SLIDE 31

TECHNICAL PERFORMANCE - AIRCRAFT

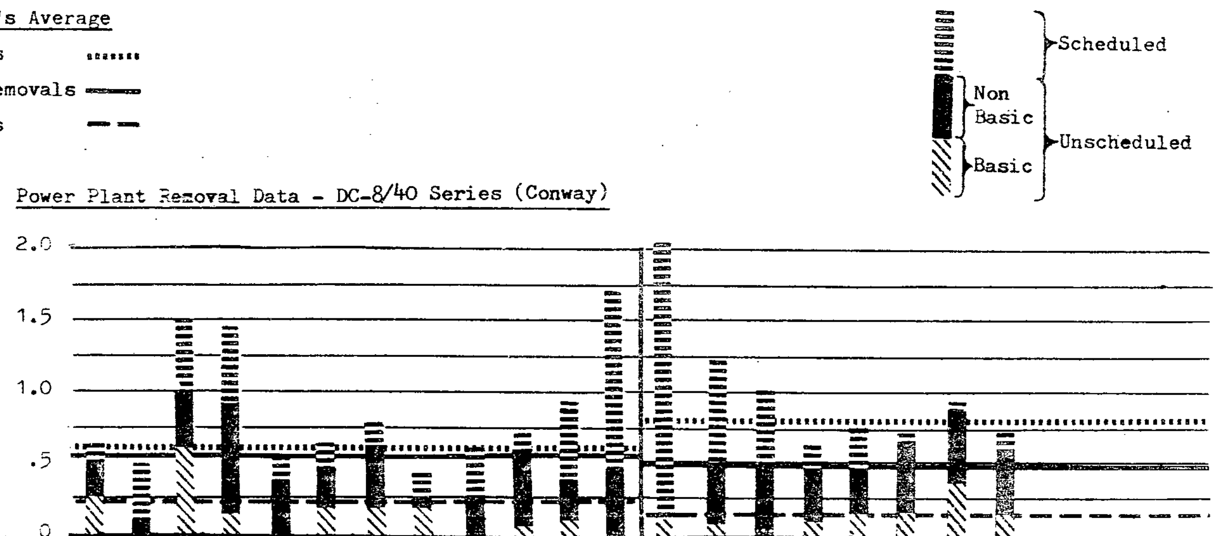
Previous Year's Average

Total Removals

Unscheduled Removals

Basic Removals

Power Plant Removal Data - DC-8/40 Series (Conway)



Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Total Removal Rate per 1000 Engine Hours	.57	.47	1.5	1.4	.50	.60	.77	.38	.59	.67	.86	1.7	2.1	1.2	1.0	.64	.75	.73	.86	.74				
Unscheduled Removals per 1000 Engine Hours	.49	.10	1.0	.89	.37	.46	.58	.25	.26	.54	.38	.42	.06	.49	.46	.43	.48	.66	.79	.60				
Unscheduled Removals	6	1	12	11	6	7	9	4	4	8	4	5	1	6	6	6	7	9	11	8				
Scheduled Removals	1	-	6	6	2	2	3	2	5	2	5	15	25	9	7	2	4	1	1	2				
Total Removals	7	5	18	17	8	9	12	6	9	10	9	20	26	15	13	8	11	10	12	10				

1 9 6 7   1 9 6 8

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THE RELIABILITY OF THE QUASAR COLOR TELEVISION RECEIVER

RICHARD A. KRAFT

MOTOROLA INC., CONSUMER PRODUCTS DIVISION,
PRODUCT MANAGER, COLOR TELEVISION

N 36738

"QUASAR" IS THE NAME MOTOROLA SELECTED TO BE APPLIED TO AMERICA'S FIRST PRODUCTION TRANSISTORIZED COLOR TELEVISION, INTRODUCED TO THE PUBLIC IN JUNE OF 1967 - ALMOST TWO YEARS AGO. THIS ADVANCED, STATE-OF-THE-ART RECEIVER WAS DESIGNED AND MANUFACTURED TO MAKE THE RELIABILITY AND PERFORMANCE CAPABILITIES OF SOLID STATE DEVICES AVAILABLE TO COLOR TELEVISION CONSUMERS. IN ADDITION, IT WAS DESIGNED TO INCLUDE UNIQUE FEATURES FOR FAST, ECONOMICAL MAINTAINANCE.

AS EARLY AS THE MIDDLE 1950'S, MOTOROLA ENGINEERS WERE ACTIVELY INVOLVED IN ADVANCED ENGINEERING PROJECTS DIRECTED TOWARD THE DEVELOPMENT OF CIRCUITS AND SOLID STATE DEVICES WHICH COULD MAKE POSSIBLE ALL SOLID STATE TELEVISION. HOWEVER, LIMITED DEVICE TECHNOLOGY, WITH CONSEQUENT HIGH COST AND MARGINAL PERFORMANCE, RULED OUT THE POSSIBILITY OF A BREAKTHRU AT THAT TIME. YET, EVEN THOUGH A PRODUCTION PRODUCT WAS NOT ACHIEVED, MUCH VALUABLE EXPERIENCE WAS GAINED. IN PARTICULAR, A NUCLEUS OF EXPERTISE IN SOLID STATE TECHNOLOGY WAS DEVELOPED WITHIN THE ENGINEERING GROUPS, READY FOR THE TIME WHEN THE TECHNICAL AND ECONOMIC FACTORS WOULD MERGE TO MAKE SOLID STATE TELEVISION POSSIBLE. AT THE SAME TIME, SPECIFICATIONS WERE DEVELOPED WHICH MADE IT POSSIBLE FOR THE ENGINEERS TO COMMUNICATE THEIR DEVICE NEEDS, BOTH PERFORMANCE AND RELIABILITY, TO THE TRANSISTOR DESIGNERS.

BASED ON OUR KNOWLEDGE, A PROGRAM WAS INSTITUTED TO EVOLVE TOWARD THE ULTIMATE ALL SOLID STATE RECEIVER. THIS PROGRAM WAS DIRECTED TO APPLY SOLID STATE DEVICES TO REPLACE VACUUM TUBES WHEREVER PRACTICAL AS SUITABLE SOLID STATE DEVICES AND CIRCUITS WERE DEVELOPED. THE FIRST RESULT OF THIS PROGRAM WAS A BLACK AND WHITE RECEIVER INTRODUCED IN 1966, WHICH UTILIZED ELEVEN (11) TRANSISTORS IN THE SIGNAL PROCESSING CIRCUITRY OF THE CHASSIS. THIS WAS FOLLOWED BY AN ALL SOLID STATE (INCLUDING ONE RECTIFIER TUBE AND PICTURE TUBE) LARGE SCREEN BLACK AND WHITE RECEIVER, AND THEN BY THE ADVANCED QUASAR COLOR TELEVISION, USING 62 TRANSISTORS <u>AND</u> AN INTEGRATED CIRCUIT.

YOU MIGHT ASK, "WHY THE GREAT PRESSURE TO REPLACE CONVENTIONAL RECEIVING TUBES IN TELEVISION?" RECEIVING

TUBES, WITH THEIR DELICATE MECHANICAL STRUCTURE AND THEIR INHERENT LIMITED LIFE CAUSED BY CATHODE WEAR OUT, HAVE BEEN THE PRIMARY CAUSE OF FAILURE IN ELECTRONIC APPARATUS SINCE THE BIRTH OF THE ELECTRONIC AGE. THE COMPLEXITY OF TELEVISION, AND ESPECIALLY COLOR TELEVISION, HAS MULTIPLIED THE PROBLEM. FAILURE RATES WHICH CAN BE TOLERATED IN A FIVE (5) TUBE RADIO, BECOME EXCESSIVE IN A 20 TUBE COLOR TELEVISION RECEIVER. TRANSISTORS, WITH NO CATHODE TO BURN OUT, HAVE A LIFE EXPECTANCY FAR IN EXCESS OF VACUUM TUBES AND IN ADDITION, DO NOT DETERIORATE IN PERFORMANCE DURING THEIR LIFE AS TUBES DO. AS A RESULT, SOLID STATE RECEIVERS CAN OFFER EXTENDED LIFE AT PEAK PERFORMANCE AS COMPARED TO TUBE RECEIVERS.

THIS IS NOT TO IMPLY THAT SOLID STATE DEVICES CAN NEVER FAIL. MANUFACTURING TECHNIQUES ARE NOT PERFECT, AND APPLICATION PROBLEMS CAN SUBJECT A PERFECTLY GOOD DEVICE TO EXCESSIVE POWER OR VOLTAGE STRESS.

YET, OVERALL, THE ELECTRONICS INDUSTRY HAS FOUND THAT THE WELL ENGINEERED APPLICATION OF SOLID STATE DEVICES RESULTS IN IMPROVED RELIABILITY, AND <u>ALL</u> MAJOR TELEVISION MANUFACTURERS ARE MAKING SUBSTANTIALLY INCREASED USE OF SOLID STATE DEVICES IN THEIR NEW CHASSIS DESIGNS.

OUR RESEARCH SHOWS THAT POTENTIAL COLOR TELEVISION CUSTOMERS RATE "EXPECTED RELIABILITY" VERY HIGH IN THEIR LIST OF THEIR CONSIDERATIONS BEFORE BUYING A PARTICULAR BRAND RECEIVER. WE FIND ALSO THAT THEY RATE "SERVICEABILITY" VERY HIGH. THIS SEEMING PARADOX IS NOT SO HARD TO UNDERSTAND WHEN YOU CONSIDER THAT IN COMBINATION THESE TWO ATTRIBUTES CAN PROVIDE LONG ENTERTAINMENT SERVICE WITHOUT UNDUE "DOWN TIME" OR EXPENSE IN THE EVENT MAINTAINANCE IS REQUIRED. IN ADDITION, THE SOPHISTICATED CONSUMER RECOGNIZES THE COMPLEXITY OF THE PRODUCT WHICH HE IS BUYING AND THE CONSEQUENT PROBABILITY THAT SERVICE <u>MAY</u> BE REQUIRED AT SOME TIME DURING THE USEFUL LIFE OF THE RECEIVER.

OUR RESEARCH ALSO SHOWS THAT THE LARGE SCALE INTRODUCTION OF COLOR TELEVISION, AND ESPECIALLY SOLID STATE COLOR TELEVISION, INTO THE FIELD IS STRAINING THE CAPACITY OF SERVICE TECHNICIANS TO PROPERLY HANDLE THE SERVICE REQUIREMENTS. THERE IS A SERIOUS PROBLEM IN FILLING THE ESTIMATED NEED FOR 20,000 NEW SERVICE TECHNICIANS PER YEAR, IN ADDITION TO THE HURCULEAN TASK OF TRAINING THOSE NOW IN THE BUSINESS IN THE NEW TECHNOLOGY.

MOTOROLA RECOGNIZED THE PROBLEM, AND ATTACKED IT CREATIVELY THOUGH THE APPLICATION OF THE PLUG-IN MODULAR PANEL DESIGN WITH TEN (10)

CIRCUIT PANELS.

THESE PLUG-IN CIRCUIT PANELS MAKE IT POSSIBLE FOR SERVICE TECHNICIANS TO REPLACE MAJOR FUNCTIONAL CIRCUIT ELEMENTS IN THE FIELD BY PLUGGING IN A REPLACEMENT CIRCUIT PANEL. THE DEFECTIVE PANEL CAN THEN BE HANDLED IN TWO WAYS: (1) IT MAY BE RETURNED TO THE FACTORY, THROUGH THE LOCAL WHOLESALE DISTRIBUTOR, IN EXCHANGE FOR A REPLACEMENT PANEL. THIS EXCHANGE IS FREE OF CHARGE WHILE THE RECEIVER IS IN WARRANTY. OUT OF WARRANTY PANELS WILL BE EXCHANGED AT A REASONABLE CHARGE. THE MANUFACTURERS SUGGESTED RETAIL EXCHANGE PRICES RANGE FROM A LOW OF $6.25 TO A HIGH OF $14.00, DEPENDING THE SPECIFIC PANEL REPLACED. (2) THE DEFECTIVE PANEL CAN BE REPAIRED BY THE SERVICE TECHNICIAN HIMSELF. ALL CONVENTIONAL SERVICE AIDS HAVE BEEN INCLUDED - TEST POINTS, COMPONENT IDENTIFICATION, AND WIRING IDENTIFICATION ON BOTH SIDES OF THE ETCHED PANELS - SO THAT QUALIFIED, TRAINED TECHNICIANS CAN APPLY THEIR NORMAL EQUIPMENT AND REPAIR TECHNIQUES IF THEY DESIRE.

OR BECAUSE OF THIS FLEXIBILITY, THE MODULAR APPROACH IS A MAJOR STEP TOWARD ANSWERING SERVICE PROBLEMS.

THE AUDIO MODULE IS A TYPICAL EXAMPLE. IT IS APPROXIMATELY 3" - 5" IN SIZE. ON IT ARE THE COMPONENTS REQUIRED TO PERFORM THE FUNCTION OF PROCESSING THE SOUND SIGNAL UP TO THE SOUND OUTPUT. IT INCLUDES RESISTORS, CAPACITORS, COILS, AND SOLID STATE DEVICES. ONE OF THE SOLID STATE DEVICES IS AN INTEGRATED CIRCUIT, WHICH INCLUDES CIRCUITRY USING 12 TRANSISTORS, 12 DIODES, AND 15 RESISTORS ON A SILICON CHIP - APPROXIMATELY 150/1000 OF AN INCH SQUARE.

THE MODULE IS CONNECTED TO THE RECEIVER THRU TWO FIVE (5) PIN PLUGS, PLUS TWO (2) SINGLE CONNECTOR RF PLUGS.

THE MODULAR APPROACH INHERENTLY ADDS MANY ELECTRICAL CONTACTS ABOVE A CONVENTIONAL CHASSIS APPROACH. THESE IN THEMSELVES CAN CREATE A RELIABILITY PROBLEM IF NOT PROPERLY ENGINEERED. FOR THIS APPLICATION IN COLOR TELEVISION, A SPECIAL VERSION OF THE AMPMODU TERMINATION WAS DEVELOPED. THESE WERE SELECTED TO MEET THE FOLLOWING SPECIFICATIONS: (1) LOW CONTACT RESISTANCE, (2) OPERATIONAL AT TEMPERATURES FROM +100°C. TO -40°C., (3) OPERATIONAL AFTER HUMIDITY TESTING AT 90°C. AND 80% R.H., (4) ENGAGEMENT FORCE TO BE ADEQUATE AND YET NOT TO PRODUCE EXCESSIVE SEPARATION FORCE, CONSIDERING POSSIBLE MULTIPLES OF AS MANY AS 30 TERMINATIONS PER BOARD, (5) ABILITY TO WITHSTAND VIBRATION AND IMPACT REQUIREMENTS OF SHIPPING,

(6) OPERATIONAL IN SPITE OF REASONABLE DEGREES OF MIS-ALIGNMENT OR DISTORTION DUE TO HANDLING OR VARIATIONS IN THE PRINTED CIRCUIT PANEL DUE TO COMMERCIAL TOLERANCES OVER A SPAN OF AS MUCH AS NINE (9) INCHES, (7) ADAPTABILITY TO PRINTED CIRCUIT BOARD CON-STRUCTION AND AUTOMATED IN-SERTION, (8) COSTS THAT ARE FEASIBLE FOR THE CONSUMER TELEVISION MARKET, (9) CAPA-BILITY OF EASY ASSEMBLY, PREFERABLY SNAP-ON INSER-TION TO LEND THEMSELVES TO HARNESS CONSTRUCTION, (10) PRO-VIDE MAXIMUM FLEXIBILITY FOR CIRCUIT LAYOUT, (11) SUIT-ABILITY TO WIRE WRAP THE POST PORTION OF THE TERMINA-TION.

COMMERCIAL TERMINATIONS WERE CAREFULLY STUDIED. EDGE CONTACTS WERE REJECTED BE-CAUSE EDGE INSERTION DOES NOT ALLOW THE USE OF ALL FOUR BOARD EDGES NOR DOES IT ALLOW THE MOST EFFICIENT USE OF BOARD AREA FOR CIRCUITRY.

THE AMPMODU TERMINATION WAS FINALLY SELECTED, FUL-FILLING MOST PARAMETERS.

MOTOROLA HAS ASSUMED THAT SERVICE WILL BE ACCOMPLISHED PRIMARILY THROUGH MODULE RE-PLACEMENT AND HAS INCLUDED THE MODULES IN A UNIQUE "DRAWER" FOR MAXIMUM ACCESS-ABILITY. THIS COMPACT CHASSIS PACKAGE IS COMPARABLE IN SIZE TO A SMALL SUITCASE. IN ONE ARRANGEMENT, THE "DRAWER" SLIDES OUT THE FRONT OF THE CABINET ON TWO BUILT IN RAILS. WITH THIS CONCEPT, MOST RE-CEIVER "SET UP" PROCEDURES CAN BE ACCOMPLISHED FROM THE FRONT OF THE RECEIVER WHILE VIEWING THE PICTURE DIRECTLY. SERVICE CONTROLS ARE AT THE TECHNICIANS SIDE FOR MOST ACCURATE ADJUSTMENT.

SWINGING OUT THE SIDE PANEL EXPOSES THE TEN (10) PLUG IN MODULES FOR INSPEC-TION AND POSSIBLE REPLACE-MENT.

A COMPREHENSIVE FIELD SUPPORT PROGRAM HAS BEEN DEVELOPED. THIS INCLUDES: (1) A SERVICE PROCEDURES BOOKLET, PACKED INSIDE OF EACH RECEIVER WHICH EXPLAINS THE METHOD OF SERVICING THE RECEIVER BY MODULE REPLACE-MENT. IT PRESENTS THE MECH-ANICAL AND ELECTRICAL LAYOUT OF THE RECEIVER, AND PRO-VIDES A SERIES OF CHARTS DESIGNED TO GUIDE A TECH-NICIAN QUICKLY TO A DEFECT, EVEN WITHOUT KNOWLEDGE OR TRAINING IN SOLID STATE CIR-CUITRY, (2) A MODULE CADDY, SIMILAR IN APPEARANCE AND SIZE TO A "TUBE" CADDY, BUT INCLUDING INSTEAD A COMPLETE SET OF MODULAR PANELS, ALONG WITH A METER AND COMPLETE SERVICE LITERATURE FOR IN-HOME SERVICE, (3) A COMPLETE MODULAR PANEL EXCHANGE PRO-GRAM WITH ADEQUATE FIELD INVENTORY FOR FAST EXCHANGE SERVICE, (4) A COMPLETE PROCEDURE FOR ON THE BENCH, SINGLE PANEL SERVICE.

THESE AIDS, ALONG WITH AN AGGRESSIVE AND COMPREHENSIVE SERIES OF TRAINING SEMINARS HELD IN THE FIELD HAVE MADE POSSIBLE SERVICE OF A QUALITY AND SPEED WHICH COULD NOT HAVE BEEN ACHIEVED WITH A CONVENTIONAL SINGLE UNIT, NON-MODULAR CHASSIS APPROACH.

YOU MIGHT ASK IF THESE BENEFITS ARE ACTUALLY REALIZED IN THE FIELD. A RECENT ARTICLE PUBLISHED IN MART MAGAZINE EXPRESSES, I BELIEVE, A WIDELY HELD VIEWPOINT. THE DEALER INTERVIEWED SAID THAT AN IMPORTANT CHANGE IS TAKING PLACE IN COLOR TELEVISION. "THE MODULAR APPROACH IN THE MOTOROLA 'QUASAR' SETS IS A GREAT THING," HE SAID, "AND THEY HAVE PRETTY WELL TAKEN THE BUGS OUT OF THE LATEST SETS. SINCE TIME IS ALL-IMPORTANT IN SERVICING COLOR OR ANY TYPE OF TV, THE QUICK CHANGE FEATURE HAS SAVED US AND OUR CUSTOMERS MANY DOLLARS.

"WE HAD A TRANSFORMER BOARD THAT SHORTENED AND BURNED UP, WHICH TOOK ABOUT 15 MINUTES TO CHANGE. OF COURSE THE BOARD WAS UNDER WARRANTY AND DIDN'T COST US OR THE CUSTOMER ANYTHING. BUT EVEN IF IT WERE OUT OF THE TWO-YEAR WARRANTY MOTOROLA OFFERS, IT WOULD HAVE BEEN, AT MOST, A $25.00 JOB. TO REPLACE THOSE COMPONENTS IN A CONVENTIONAL TUBE SET WOULD HAVE BEEN OVER $100.00, AND THE CUSTOMER WOULD HAVE OBJECTED.

THESE KIND OF COMMENTS INDICATE TO US THAT OUR PIONEERING EFFORT IS ACHIEVING THE RESULTS THAT WE HAVE BEEN STRIVING FOR IN PRODUCT SERVICEABILITY.

ALL OF THESE PRODUCT BENEFITS AND CONSUMER ORIENTED PROGRAMS, NO MATTER HOW OBVIOUSLY GOOD THEY ARE, MUST BE COMMUNICATED TO THE POTENTIAL BUYER IN A FORM WHICH WILL MOTIVATE HIM TO BUY. A WELL TESTED AND INTELLIGENTLY APPLIED MARKETING PROGRAM HAS BEEN SUCCESSFULLY IMPLEMENTED IN 120 MARKETS.

PROPERLY TARGETED MARKETING STARTS WITH ADEQUATE KNOWLEDGE OF THE CONSUMER. WE GAINED THIS NEEDED INFORMATION THROUGH IN-DEPTH INTERVIEWS CONDUCTED IN THE HOMES OF BLACK & WHITE TELEVISION OWNERS SELECTED TO COVER ALL SEGMENTS OF THE POPULATION IN 10 MAJOR CITIES.

THROUGH THIS RESEARCH WE FOUND THAT CONSUMER HOLDOUTS WERE NOT BUYING COLOR TELEVISION BECAUSE THEY FELT IT WAS NOT PERFECTED, THAT IT WAS NOT RELIABLE AND REQUIRED TOO MUCH SERVICE AND THAT SERVICE MEANT THE SET HAD TO LEAVE THE HOME -- OFTEN FOR LONG PERIODS OF TIME.

BECAUSE THESE CONSUMERS PRIMARILY BUY ON TIME, THEY ARE MORE CONCERNED WITH UNEXPECTED SERVICE COSTS FOR

WHICH NO BUDGET CAN BE SET THAN ABOUT THE INITIAL COST OF COLOR TELEVISION. IN FACT, THEY ARE WILLING TO PAY MORE, IF ASSURED RELIABILITY AND EASE OF SERVICE. ABOVE ALL, THEY DO NOT WANT TO LOSE THE SET FOR A LONG PERIOD BECAUSE OF NEEDED REPAIRS. THEY WANT QUICK, IN-HOME REPAIR.

WITH THIS BACKGROUND, WE SET OUT TO CONCEPT TEST VARIOUS IDEAS TO DETERMINE THE SELLING APPROACH THAT WOULD BEST MOTIVATE COLOR HOLDOUTS TO BUY "QUASAR" TELEVISION. FROM THIS CONCEPT TESTING WE LEARNED THAT THE NAME "QUASAR", WHILE NOT UNDERSTOOD BY THE CONSUMER, WAS BOTH INTRIGUING AND MEMORABLE.

EVEN MORE IMPORTANT WE FOUND THAT THE PHRASE "WORKS IN A DRAWER" HIT HOME WITH THE CONSUMER AND DRAMATICALLY DEMONSTRATED AN EASILY UNDERSTOOD DIFFERENCE BETWEEN QUASAR AND ORDINARY COLOR SETS.

TO VALIDATE OUR RESEARCH, WE THEN MARKET TESTED OUR PROGRAM IN NINE (9) MAJOR CITIES, INCLUDING BUFFALO, STARTING IN LATE 1967 AND CONTINUING THROUGH THE FIRST HALF OF 1968. TO BE CERTAIN ANY INCREASES IN THE TEST MARKETS COULD BE DIRECTLY AND TOTALLY ATTRIBUTED TO OUR NEW "QUASAR" PROGRAM, WE SET UP CONTROL MARKETS WHERE BUSINESS AS USUAL WAS CONDUCTED.

IN BOTH TEST AND CONTROL MARKETS, WE CAREFULLY AND THOROUGHLY MEASURED RETAIL SALES OF ALL TV BRANDS BEFORE, DURING AND AFTER OUR PROGRAM PERIODS.

AS A FURTHER TEST, WE VARIED THE AMOUNT OF ADVERTISING WEIGHT BROUGHT TO BARE AGAINST DIFFERENT GROUPS OF TEST MARKETS TO DETERMINE THE MOST EFFECTIVE AND EFFICIENT LEVELS FOR PRODUCING INCREASED SALES.

AWARENESS OF MOTOROLA ADVERTISING INCREASED IN THE TEST MARKETS BY AN AVERAGE OF 52 PERCENT. THERE WAS NO CHANGE IN THE CONTROL MARKETS. INTENT TO SHOP WAS UP 71 PERCENT AS REVEALED BY EXTENSIVE TELEPHONE SURVEYS, BUT NO SUCH CHANGE OCCURRED IN THE CONTROL CITIES.

MOST IMPORTANTLY, OUR PENETRATION GAINED AN AVERAGE OF 30 PERCENT IN THE IMPORTANT AND PROFITABLE HIGH END COLOR SALES MARKETS.

BASED ON THIS SUCCESS, THE PROGRAM WAS LAUNCHED NATIONALLY IN SOME 120 MARKETS STARTING IN LATE SEPTEMBER 1968, USING CONCENTRATED WAVES OF SPOT TV AND REGULAR INSERTIONS OF LARGE SPACE ADS --- SOME IN FULL HI-FI COLOR -- IN THE LARGEST CIRCULATION NEWSPAPERS FROM COAST TO COAST.

CONCURRENTLY, ANOTHER EXTENSIVE RESEARCH PROJECT

WAS BEGUN IN CITIES LARGE AND SMALL WITH THE FIRST PHASE CONDUCTED JUST BEFORE THE START OF ADVERTISING IN SEPTEMBER -- THE SECOND PHASE IN LATE DECEMBER AFTER THE CONCLUSION OF 1968 ADVERTISING.

THE RESULT! MOTOROLA ROSE FROM FIFTH PLACE IN AWARENESS TO SECOND PLACE -- A TRULY DRAMATIC INCREASE FROM JUST TEN WEEKS OF ADVERTISING IMPACT. "WORKS IN A DRAWER" WAS REMEMBERED AT A LEVEL OF AT LEAST 2-1/2 TIMES BETTER THAN THE BEST COPY ELEMENT OF OTHER LEADING MANUFACTURERS.

WE OF COURSE, PLAN TO CONTINUE THE QUASAR APPROACH NOT ONLY INTO THE FALL OF 1969 ON AN EXPANDED BASIS BUT ON INTO THE FUTURE.

WHILE ADVERTISING REPRESENTS THE MAJOR THRUST OF OUR QUASAR MARKETING PROGRAM OTHER MERCHANDISING ACTIVITIES ARE PROPERLY INTERFACED. FOR EXAMPLE, HUNDREDS OF MEETINGS HAVE BEEN HELD WITH RETAILERS -- PROSPECTIVE AS WELL AS ACTIVE ACCOUNTS - TO EXPLAIN OUR PROGRAM AND TO SOLICIT THEIR SUPPORT. MANY NEW ACCOUNTS HAVE BEEN ADDED AS A RESULT OF SUCH MEETINGS.

PHONE CALLS TO CONSUMERS AFTER THEY BUY TO ASCERTAIN HOW THEY LIKE THEIR QUASAR TV HAS BEEN A PARTICULARLY UNIQUE PART OF OUR TOTAL PROGRAM. THIS CONCERN WITH THE CONSUMER'S SATISFACTION HAS CREATED UNUSUAL GOOD WILL AND HAS PRODUCED ADDITIONAL WORD-OF-MOUTH SALES.

THE "QUASAR" MARKETING PROGRAM, WHICH STARTED NATIONALLY ONLY LATE LAST SEPTEMBER, HAS PRODUCED THE RESULTS THE TEST MARKETING INDICATED COULD BE EXPECTED AND IN THE FOURTH QUARTER OF 1968, MOTOROLA SUBSTANTIALLY INCREASED ITS SHARE OF THE $600.00-AND-OVER RETAIL PRICE COLOR TELEVISION MARKET, AS COMPARED TO THE SECOND QUARTER OF LAST YEAR. OUR SHARE OF MARKET CONTINUED TO MOUNT IN THE FIRST QUARTER OF 1969 AND WE BELIEVE WE ARE CLOSING IN ON THE NUMBER TWO SELLER OF COLOR TELEVISION IN THE IMPORTANT HIGH END CONSOLE SEGMENT OF THE MARKET.

ADDITIONALLY, OUR TOTAL SHARE OF COLOR TV MARKET HAS INCREASED STEADILY SINCE THE QUASAR MARKETING PROGRAM WAS LAUNCHED NATIONALLY LAST SEPTEMBER.

IN CONCLUSION, MOTOROLA IS COMPLETELY CONVINCED OF THE BENEFITS OF THE QUASAR PRODUCT APPROACH, STRESSING THE APPLICATION OF SOLID STATE RELIABILITY TO CONSUMER PRODUCTS, COMBINED WITH UNIQUE SERVICE FEATURES

WHICH CAN HELP MAKE POSSIBLE IN HOME SERVICE THROUGH MODULAR PANEL REPLACEMENT. WE ARE CONFIDENT OF THE POWER OF THIS PROGRAM, AND WILL BE ACCELERATING AND EXPANDING IT FOR THE FUTURE.

CURRENT APPROACHES TO UNIFORM TIRE BUILDING

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In recent years there have been many discussions related to the demands on tires and how to accurately measure these demands to determine if uniformity of product has been obtained. The key to this problem is .....How? Many people outside of the tire industry have been willing to talk and write about WHY tires should be more uniform, but nobody, particularly we involved in the industry, would want to refute the validity of these claims and conclusions, but we always come back to HOW?

Realistically speaking, uniformity is not sufficiently inclusive. When most people speak of tire uniformity, they are referring to a tire quality level which will result in a smooth, quiet, soft ride,but realistically this cannot be separated from factors such as handling, wear and safety. Uniformity as it is known within the industry requires initiative and creativity in addition to new methods, materials, machines, and money.

If the recent commotion over tire standards and tire uniformity has achieved nothing else, it has increased our awareness of the complexity and importance of the pneumatic tire. The public has, in the past, taken the tire for granted and have been confused by the use of the word, "build" in relation to the production of tires. If there was any thought outside the industry of how tires were produced, the mental image would be some kind of a machine that pressed out tires like doughnuts and then formed them, using tricky and characteristic tread patterns in some kind of a mold.

The industry has, in fact, directed their efforts by taking the specifications and the available equipment as starting points, and designing tools and equipment to not only meet the more stringent requirements placed upon tires today.....but also to produce a more uniform tire without sacrificing economy. Many changes have taken place in recent years in tire design, materials, and building equipment.... But the demand for uniformity increases and further knowledge of HOW to achieve this is required.

Returning to the complexity involved in the building of a tire.... the tire is composed of many parts and so the word "building" is well chosen. The uniformity of each component is important - but the final assembly is even more important in terms of safety, satisfaction, and economy.

It has been said that "the tire is the most complicated single component in the automobile". That is a very significant statement, so, when we think of tooling up to make tires, we must consider a high degree of precision. With the numerous components in a tire, and the inevitable variations that occur in hand preparation and hand assembly, the desired and required uniformity of today must be obtained with the assistance of precision equipment.

The need for building tires of greater uniformity may be summarized under the heading of....

1. Desirable Features, which include riding characteristics, smoother ride, quieter ride with no squeal, and appearance.

2. Safety Features, which include improved traction and braking on wet surfaces, better aging and weathering resistance, and improved handling and wear.

3. Economic Features, which include factory rejects, field adjustments and the eventual cost to the public.

As we have examined the need for greater uniformity...let us now consider three means by which this uniformity can be achieved.

First, a tire or a tire-wheel suspension system could be developed for the vehicle which would allow greater tolerances for or better reduction of, disturbances arising from non-uniformity in the tire.

A second method, actively being pursued by the industry, is to produce a tire in the best possible manner with the materials, methods and equipment available...but to incorporate some method for fine tuning or adjustment to eliminate minor various variations.

A tire is unique...in that it is one of the few products which must have all of the uniformity and precision built into it...whereas such products as TV's or appliances can undergo a greater degree of tuning and adjustment after coming off of the production line. However, recent equipment advances make it possible to automatically balance tires before leaving the plant by grinding portions of the tread surface.

The third procedure is to design this and produce equipment that with automatic uniformity to a large extent, and eliminate many of the possibilities for human error, but particularly minimizing the variables that naturally occur from station to station in the "building" process. When a completely uniform method of manufacturing is accomplished, a final tuning and adjustment procedure would be advisable and rewarding, especially if performed on the vehicle wheel. One tire manufacturer has recently publicized a tire having a narrow Fibreglas belt above the head. This allows the utilization of a much narrower rim, from which the tire would not be separated even with a massive failure.

Let us now examine those stations of tire building which are equal in importance to the final assembly and curing operations. It should be recognized that the tire bead is the member which transmits the load from the tire to the rim, and its strength and uniformity are of prime importance. Presently continuous magnetic monitoring procedures are used to insure proper physical properties --this is a significant improvement over formerly utilized sampling techniques. Precision winding of programmed beads is a method which produces a bead that is more flexible, has a more desirable cross-section, and minimizes effects of wire ends in addition to being stronger for a given amount of wire. Another operation which makes a significant contribution to bead uniformity is that of the cover or wrapping operations to provide controlled and uniform splices. In order to assure proper bead dimensions, a bead checking feature is imperative, and considerable interest exists in equipment now available for measuring bead compression.

Uniformity in the compounding and mixing of rubber is another important step in the tire building process. Improvements have been made in recent years in procedures for sampling and testing raw materials and for automatically weighing and charging materials into mixers. It seems obvious, however, that sooner or later, the rubber industry must move from batch processing to continuous compounding, and recent developments in the form of continuous mixers and extruders offer possibilities to this end. Due to the great difference inweight and volume ratios of some parts of the rubber compound, such as that of the rubber to other small but important quality ingredients, the weighing and metering equipment required for continuous compounding will have to achieve accuracy many times better than that now available. In addition, there needs to be developed some means for continuously measuring the composition of the mixed compound for immediate feedback of error so that very rapid corrections can be made to keep the stock within specified tolerances.

The production of the tread portion of tires by the conventional extrusion process has been improved in recent years, but the process itself induces strain and thermal stresses to the uncured extrudite, which can result in additional non-uniformities. In addition, this method requires a splice when the tread is formed into a band on the tire building drum and a splice in any mechanical structure is always a potential source of non-uniformity and weakness. For this reason, alternate methods of applying the uncured tread rubber to the curing drum have been developed such as ribbon, strip and sheet treading which will be mentioned later.

In tire building, there are some requirements which are so basic that they sometimes tend to be overlooked. These requirements include: (1) that the drum be circular, always expanded to the same diameter and run true, (2) that the beads be placed square and concentric with the drum and (3) that the plies and tread be run on square and centered and with uniform tension. To meet these requirements, the tire assembly machine has become a precision device..built like a machine tool with a rugged bead stock and tail stock arrangement, and precision centering and guilding devices for the bead placing rings. Precision radial expanding type drums capable of holding dimension and run-out tolerances within very close limits have been adopted along with drum collapsing and expanding mechanisms which eliminate the damage caused by earlier inertia collapse devices.

I recall upon my first visit to a tire plant I was surprised at the number of hand operations, particularly in the tire assembly operation. The tire industry is not unique in this because assembly is one of the last and most difficult areas to be attacked by automation. An example of this is the automobile industry where such items as engine blocks are machined and checked completely automatically, while vehicle assembly still utilizes a large number of people using hand-operated devices. Attempts to mechanize tire assembly have generally met with one of the following stumbling blocks:

1. The system wasn't flexible enough to meet production demands and changes in product construction.

2. The mechanized production system and product design were not mutually compatible.

3. The system attempted to automate or mechanize every operation thus making it exceedingly complex, expensive and unreliable.

In recent approaches, mechanization has been directed to those areas that best lend themselves to this approach with normal operations being retained in areas where mechanization has proved to be impractical. In the manual operations, provisions must be made to limit the variability due to human factors.

In the tire industry it is now accepted that production methods must be considered as one of the basic requirements in creating a product design. Tolerances must be developed on the basis of proven requirements because unless realistic tolerances and simplified construction are designed into the product, the resulting production equipment may carry a prohibitive price tag, be complex, and unreliable, and finally self-defeating.

As mentioned earlier, one major contribution to tire building is sheet treading. Rather than extruding tread to size, cutting it to length and splicing it, the tread is programmed onto the tire in successive wraps in sheet form. This eliminates the splice problem, reduces the possibility of tread separations and permits a wide range of tread shapes. In time it may be possible to automate the tire building process which assembles the innerliner, plies and beads on the building drum and then applies the tread by the sheeting method.

Other advances evident in the past decade are in the curing room. Despite these improvements, there are still many uniformity problems involved in curing. Those problems requiring further attention include: elimination of curing bladders, uniform thermal conditions at the molds and in the post - cure inflation area; and the development of a cure monitoring device which would indicate when the tire is properly cured.

In years past a cured tire was a finished tire. This is no longer true, and perhaps as much work goes into a tire after curing as prior to being cured. In addition to inspection, trimming, precision sidewall grinding, balancing, tire uniformity grading and tire uniformity optimizing, there are numerous tests carried out on samples and sections of produced tires. Additional techniques now being used or proposed include: X-ray inspection and the use of ultrasonics.

Recent changes in tire design and construction have made a considerable contribution to both the uniformity and reliability of the tire. There has been a decided movement on the part of the automobile manufacturers to go the belt/bias (2+2) type of tires for original equipment. This tire, as a result of reduced trend squirm and flexure, provides an improvement in tread wear and traction through trend design flexibility. The radial tire would have accomplished the same purpose. However, the U.S. tire industry in my opinion was opposed to going to the full radial tire.

It would have required a major capital outlay for new tire building equipment. In addition, with the present emphasis on tire uniformity the ability of the tire industry to produce a uniform radial tire was much more difficult. The automobile manufacturers, inaddition, found the full radial tire to be harsher at low speed with the present cam suspension system and the full radial tire would also have been more expensive.

It was interesting to note that even with the Fibreglass belt at approximately a 30° angle versus the full radial at approximately 10° to 15° the tread wear of the belt bias tire approached that of the full radial tire. The August, 1968, issue of Consumer's Guide rated certain radial and 2+2 belt bias tires to have an identical tread wear life of 40,000 miles.

It is felt that the belt/bias (2+2) tire will provide improved traction because the grooves stay open with less squirming or tread movement on the road. Because of the better treadwear, there is more flexibility in tread design to facilitate better traction.

Perhaps a few additional comments on traction would be in order. Traction which has been a very serious problem in Europe for sometime, is now becoming recognized as one if not the major problem of concern with present tires.

It is felt that the automobile manufacturers and the Federal Government will ultimately have traction requirements in their specifications. Most tire manufacturers feel that improved traction will be the result of design and construction of the tire. The rubber compound composition will not be the determining factor but rather will be modified in order to compensate for problems caused by design changes.

There exists three types of traction, namely cornering, braking, and acceleration. Cornering is probably the most critical from a safety viewpoint and also the most difficult to test definitely. Therefore, it is possible that the Federal Specifications will be written to cover braking and/or acceleration traction and result in changes which could adversely affect cornering traction.

Perhaps the ultimate answer to traction will not be the tires but instead the design and construction of materials of highway surfaces. This, of course, is a long range idea, and in the interim period tires will have to bear the brunt of improved traction.

In closing, I would like to caution that these are my personal observations and opinions based upon my association with the tire industry.